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CONTENTS

PAPERS

Paper No. 26

ARTIFICIAL WATERWAYS WHICH FORM CUT-OFFS ON MARINE ROUTES, AND WATERWAYS CONSISTING OF NATURAL CHANNELS AND BODIES OF WATER LINKED BY ARTIFICIAL CHANNELS, CONSTITUTING INSIDE ROUTES.

By

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Washington, D. C., U. S. A.

The best known examples of waterways of the first class are the Panama, Suez, Corinth, Cape Cod, and Kiel (whose strategic importance has been so well demonstrated in the present war) Canals, and the old Caledonian Canal across Scotland (now said to be obsolete), which was built by Thomas Telford and opened for traffic in 1823.

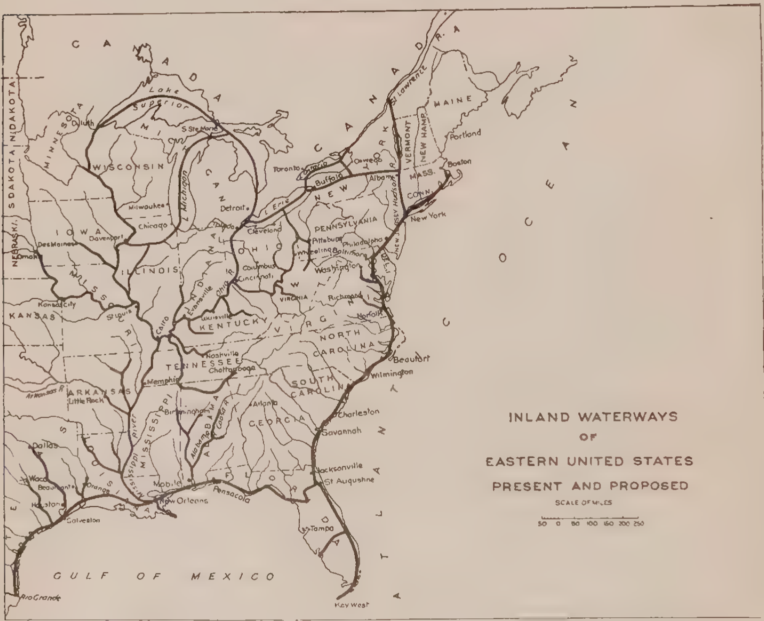
In the second class may be placed the well known canal systems in European countries, and in this country the old Erie Canal, now being replaced by the 1,000-ton barge canal, for which the original estimate was $101,000,000; the Illinois and Mississippi Canal, known as the Hennepin Canal; St. Marys Falls Canal, Welland Canal, and a number of smaller and less known examples.

These canals have been so well described in the past and are so well known that no attempt will be made to discuss them here.

There is, however, a more recent development of waterways of the second class, in this country, which has come into prominence only within the last few years and which will be described more fully here. The writer refers to the Inland Waterway along the Atlantic and Gulf coasts, popularly known as the "Intracoastal Canal".

The route, as proposed for this waterway, begins at Boston Harbor, Massachusetts, and extends along the Atlantic and

Gulf coasts through the coastal bays, sounds and rivers, and through artificial cuts connecting these natural waterways, to the Rio Grande, which forms the international boundary between this country and Mexico. It will intersect or pass close to all the navigable rivers which empty into the Atlantic and Gulf between these points, and will form with these, as tributaries, a great net-work of interior navigable waterways covering the eastern half of the United States.



This entire route has been examined and reported on by special boards of engineers, authorized by Congress, and these reports have been printed and are now public information. The route as tentatively proposed by these various special boards may be seen by a glance at the accompanying map and is briefly described as follows:

Beginning at Boston Harbor, the line will extend to either Hingham or Plymouth Harbors by natural channels, this portion of the route not yet being decided on, thence across the State of Massachusetts by an artificial cut through dry land to

the Taunton River, from which a natural channel reaches to Narragansett Bay. Between Narragansett Bay and Long Island Sound, at Fishers Island, another artificial cut is to be made paralleling very closely the coast line and passing through a chain of ponds. The route then utilizes Long Island Sound and the natural channels connecting with New York Harbor, passing through these channels and through upper and lower New York Bay to Raritan Bay, New Jersey.

Between the latter bay and Delaware River, another artificial cut will become necessary across the State of New Jersey. This cut is to enter the Delaware a short distance below Trenton. Delaware River will then be utilized to the entrance of the old Chesapeake and Delaware Canal, near Delaware City, below Philadelphia. From this point to the Chesapeake Bay, it is the intention to utilize, as far as possible, the present Chesapeake and Delaware Canal, widening, deepening and straightening it. The route then follows Chesapeake Bay to Norfolk, Virginia; thence enters the land again and utilizing, for part of the way, the old Albemarle and Chesapeake Canal, passes through to Albemarle Sound; thence through this sound and across intervening land to Pamlico Sound; thence through this sound to its lower end. The route then passes through a narrow strip of land to Beaufort, North Carolina.

From Beaufort to Jacksonville, Florida, the route parallels very closely the coast, passing through the numerous lakes, bays and rivers of that region, with cuts through land where necessary to avoid wide detours. From Jacksonville the route follows, for a short distance, St. Johns River, then strikes across the upper part of the Florida peninsula to the west coast, following for the most part rivers, lakes and bayous, but here necessitating some locks. The route enters the Gulf of Mexico near Cedar Keys, and from this point to St. George's Sound, Florida, will lie in the Gulf for a distance of about 120 miles, unless future location shall change the route inland. From St. George's Sound the line enters Apalachicola Bay, Florida; thence passes through land by an artificial cut to East Bay; thence through St. Andrews Bay, Choctawhatchee Bay, Santa Rosa Sound, Pensacola Bay, Mobile Bay, Mississippi Sound and Lake Borgne, and through the old Lake Borgne

Canal to the Mississippi River, a short distance below New Orleans. Artificial cuts will be needed in a few places through intervening land between these bays, with, of course, some dredging in the bays.

The route leaves the Mississippi again about opposite New Orleans (there are several proposed routes here, one being via the Plaquemine lock) and passes across the State of Louisiana, utilizing the numerous bayous and lakes for a great part of the distance, to Sabine River, the boundary line between Louisiana and Texas. From this point to Port Arthur, Texas, the recently constructed Sabine-Neches Ship Canal and the Port Arthur Ship Canal will be utilized. From Port Arthur to Galveston East Bay an artificial cut through land becomes necessary, although bayous and lakes are followed for part of the distance. The line then enters Galveston Bay, passes by the City of Galveston and through West Galveston Bay and the old Galveston-Brazos Canal to Brazos River; thence by a cut through land, passing through several lakes, and intersecting San Bernard River, to the head of Matagorda Bay; thence the line passes through the Matagorda Bay and through a short artificial cut to Espiritu Santo Bay. From this point the route follows the natural channel through the bays Espiritu Santo, San Antonio, Mesquite, Aransas, Corpus Christi, and Laguna Madre (which all connect) to within about 3½ miles (5.64 kilometers) of the Rio Grande, where a cut of this length through dry land becomes necessary to gain access to this river. This is the western terminus of the Inland Waterway, as it here reaches the International Boundary between the United States and Mexico.

This, in brief, is the proposed main line of the waterway. From the St. Johns River, Florida, a branch will extend down the east coast of Florida to Key West, through the interior lagoons and bays. Tapping this main line and forming feeders will be the large number of rivers and bayous running into the Atlantic and Gulf, chief among which are the Mississippi and its many tributaries.

The following table gives the projected depth and estimated cost of the various sections as proposed by the Special Boards:

Section	Projected depth Feet	Projected bottom width Feet	Estimated Cost	Remarks
Boston-Narragansett Bay	18 (5.49 m)	125 (38.1 m)	$17,453,000	Not definitely decided on. This route is via Plymouth, Mass.
Narragansett Bay-Long Island	18 (5.49 m)	125 (38.1 m)	$12,322,000	....
New York-Delaware River	25 (7.62 m)	125 (38.1 m)	$45,000,000	....
Delaware River-Chesapeake Bay	25 (7.62 m)	125 (38.1 m)	$ 9,910,210	To this should be added the cost of acquiring the Chesapeake and Delaware Canal.
Norfolk-Beaufort Inlet	12 (3.66 m)	90 (27.43 m)	$ 4,901,580	To this should be added the cost of acquiring the Albemarle and Chesapeake Canal.
Beaufort-Jacksonville (St. Johns River)	10 (3.05 m)	100 to 200 (30.48 m to 60.96 m)	$19,113,000	....
Jacksonville-St. George's Sound	....	....	....	No estimate published.
St. George's Sound-Rio Grande	5 (1.52 m)	40 to 65 (12.19 m to 19.81 m)	$ 6,632,910	....

Note: Metric equivalents shown underneath figures in feet.

The construction of the above has so far been but partially recommended by government officials. As so recommended, the route is to be:—Boston, Mass., to Beaufort, N. C., 12 feet (3.66 meters) in depth (standard with the new Erie Canal); from Beaufort, N. C., to Jacksonville, Florida, 7 feet (2.14 meters) in depth; and from Choctawhatchee Bay, Florida, to the Rio Grande, 5 feet (1.52 meters) in depth, although 9 feet (2.74 meters) is desired, in order that this section of the canal may be standard with the lower Mississippi and with the adopted plans for the improvement of the Ohio.

Portions of the waterway have been completed and are now in use, notably across the State of Louisiana from the Mississippi to Port Arthur, Texas (very nearly completed), and from Galveston, Texas, to Corpus Christi, Texas, completed to a depth of 5 feet (1.52 meters) and width of 40 feet (12.19 meters). This latter section covers the greater portion of the Coast of Texas.

Regarding the commercial advantages of the proposed waterway, the following is quoted from the two special boards of engineers on the Atlantic Sections. These remarks apply with practically equal force to the Gulf Sections.

"The general question of the advantages to be gained by opening through water-routes for the carriage of freight have been discussed in numerous reports and papers during the past few years. It is unnecessary for this board to go deeply into this subject in this report; but it may be well to touch on certain aspects.

"It is claimed that large outlays for the improvement and construction of internal waterways are uneconomical in that the service of freight carriage can be performed better and with greater economy along the coast by ocean-going lines (including steam and sail cargo vessels and ocean-going barges under tow) and internally by the railways. In support of this are cited the great development of the coastwise and Great Lakes traffic end of the railway systems and the decline, in many instances, of water-borne commerce of the rivers after parallel lines of railways have been established. It would appear to the board that such reasoning is only partly justified in fact.

"As shown in the report of the Philadelphia committee on traffic, the annual losses of life and property in the coastwise trade of the United States are appalling and are apparently unavoidable. To minimize these losses the vesssels used must be strongly built and of an expensive type. The relative cost of the type of carrier per ton is approximately as follows: (Report Special Board of Engineers on Survey Mississippi River, 1909, page 24.)

Ocean vessels	$75.00
Lake vessels	41.50
Mississippi River tug with barges for ten thousand tons of freight	12.00

"To offset the losses, marine insurance is taken out, which for an outside route runs from 8 to 12 per cent annually, as against an average of 4 per cent for an inside route. (Philadelphia report, p. 200.)

"Both of these factors make toward an increase in cost of carriage. Another increment of cost for an outside route lies in the greater time consumed, due to a longer course generally necessarily followed, and to delays incident to fog and storm.

"From figures presented the board believes that navigation by interior lines presents advantages to commerce over outside routes which vary in value for different sections, but which are sufficient in general to justify the opening of certain interior lines. . . . . .

"The history of commercial development on this coast demonstrates that utilization of an inland waterway will be of two distinct kinds, the first being that which will develop within local zones and the second being that which will pass from zone to zone; in other words, 'local' and 'through traffic'.

"(a) **Local Zone Traffic.** The board believes that development will take place first within the local zones. There are now many usable harbors on the South Atlantic Coast. The productions of the country adjacent to these harbors seek the ports as outlets, and where inland waterways now exist it is found that much commerce passes from the interior down the river systems to points of intersection with the inland waterways, and so to the nearest commercial ports. Similarly, the

harbor cities are centers of distribution for materials and supplies required in the interior. Commodities come to the ports by ocean-going ships and are distributed to the interior via the inland waterways and river systems.

"(b) **Through Traffic.** The prospect of development of through traffic is less certain, though some considerations point to favorable expectation. The advocates of this work are able to show that barge traffic is inexpensive. Such has certainly the advantage of being carried on a small rather than large container, and in this way can reach points not otherwise accessible. Similarly, the small container lends itself to use by small companies and by individuals of limited means, who, while able to receive or send barge loads, may be quite unable to charter ships, or, indeed, engage transportation on ships.

"Advocates of this improvement also state that the number of sea-going carriers now operating on the South Atlantic Coast is too small. Many instances are brought forward in which freight has been offered for shipments, only to be refused.

"The advocates also point to the fact that a through route will have an uncommonly large number of feeders in the numerous river systems of the South Atlantic States, which, in general, flow normal to the coast, intersecting the canal at their seaward ends, and thus are able to contribute a considerable water-borne commerce.

"Examining the prospect of through traffic from another point of view, there is now in evidence a large commerce in commodities such as coal, lumber, building materials, sugar, hardware, supplies, and truck which passes up and down the coast by either coast-wise steamers, schooners, or rail. While it cannot be expected that for strictly through traffic a barge canal can ultimately deflect shipments from sea-going steamships, it can be expected that freight now refused by steamships and shipped at high expense by rail will seek the barge canal as an economical outlet. And in view of the small-cargo feature freight now originating in large ports, destined for communities not reached by ocean-going steamers, should be more economically distributed from a large port than under the present system from large port to small port and thence to community."

With the possible exception of the great cut across New Jersey, and of the lock canal across Florida, the engineering questions involved in the construction of this great system of still water channels are exceedingly simple.

The development of the modern suction dredge has reduced preliminary costs and maintenance costs to a point that has put these waterways within our financial reach.

So great has been the effect of the suction dredge, that it has become far cheaper in many cases to depend upon occasional redredging for maintenance purposes than upon permanent structures of any kind.

For the canal across Florida, locks will probably be necessary; also on each side of the Mississippi. On the west side of that river, the present lock at Plaquemine will probably suffice. On the east side, a larger lock will have to be constructed.

Elsewhere, it is probable that no locks will be needed, and few permanent structures, and that reliance for maintenance can be placed upon the operation of suction dredges.

There are occasional points where storms may cause excessive shoaling in a few hours, especially where the canal opens into a large bay, as at the southern entrance to Matagorda Bay in Texas. Here jetties will remedy the trouble and can ordinarily be constructed more economically of creosoted piling than otherwise.

In the maintenance of such a canal system, the number of dredges in use should be just sufficient to remove the annual shoaling.

As this limits the number of dredges and as any single dredge can cover its territory but once a year or thereabouts, it is necessary when a dredge works at any locality, that it should dig enough deeper than the desired depth to enable this latter depth to obtain until it can return.

This means the dredging, at critical points, of from 2 to 4 feet (0.61 to 1.22 meters) greater depths than those needed for the proposed channels. These critical points soon become well known, and this policy does not involve so much excess dredging as might at first be thought.

Also, where ponds or lakes are encountered, it is better, in the general case, to carry the line around them rather than

through them, especially when their natural depth is less than that which is desired.

This is because the bottom of such ponds and lakes is generally composed of soft mud which keeps flowing into the canal and rendering its maintenance difficult. Where a dredge can constantly be within call, this is not a matter of so much importance, but where a dredge can come but once a year, or thereabouts, the shoaling that may occur at these lakes and ponds may be a serious consideration.

It would be very advantageous if, in addition to the regular dredging plant which works steadily through its section of such a canal from one end to the other and back, there could be a smaller dredge, self-propelling, if possible, which normally could be employed in snagging or other work, but which would be available for hurry calls for the removal of small amounts of shoaling which might occur at special points, and when the use of the regular dredge would entail too much cost for its special towing to and from the locality.

While the maintenance of such a canal system would involve considerable annual cost for dredging, it would be better policy to rely thereon when the annual dredging cost (capitalized) was less than the cost of such permanent structures as might maintain the works without dredging.

In the general case, with our proposed coast canal system, its maintenance by dredging will be more economical than any other course; this by reason of the great development in recent years of the suction dredge, and its economical operation per unit of material removed.

Apart from this, however, the question naturally arises as to why there should be any economy in paralleling the Atlantic Ocean and the Gulf of Mexico with a waterway.

To a landsman, the explanation is difficult, but it lies in the fact that for large bodies of open water like the Atlantic or the Gulf or even the Lakes, vessels for safe navigation must be much more staunch than for the still water of a canal or a river.

This means that ocean vessels must cost much more per ton of carrying capacity than canal or river vessels, as is recognized by the Special Board of Engineers whose report is hereinbefore quoted.

In addition, this coast canal system links together all the rivers flowing into the Atlantic and Gulf and will render possible the transportation of bulk freight without transfer from any river or coast point to any other river or coast point.

With a suitable connection between these rivers and the Great Lakes, as will soon be effected by the new Erie Canal and as is proposed at Chicago and elsewhere, and with the further improvement of our principal rivers, these canals would permit through water transportation by barge, without the breaking of bulk, between any of our leading commercial centers east of Kansas City.

The well known economies of water transportation would soon mean that all this eastern section of the United States would increase in population and prosperity, as have those in the region of the Great Lakes since adequate water transportation was created there.

Materials would move from place to place that could not otherwise be handled, and new industries based on low freight rates would come into existence.

As an example, take perishable freight, such as meats, fruits, and vegetables, not ordinarily regarded as other than fast railway freight. These would quickly seek water transport were it possible to move them long distances without transfer. The economy in a barge carrying a small cold storage plant, as compared to long trains of refrigerator cars, is so great that there can be no question as to the survival of barge transport for this character of freight, once it became possible to take barges from any important commercial center to any other in the territory mentioned.

As another illustration, it may be mentioned that the possibility of transporting coking coal from the Alabama mines to Texas points without intermediate trans-shipment would bring into commercial use the great iron ore deposits of East Texas, now undeveloped for lack of suitable fuel. In addition, the competition which such a waterway system would cause would lower railway rates between all points affected.

For nearly thirty years our legal brethren have labored through the instrumentality of National and State Commissions to lower railway rates. They have been able in the main, to

stop discriminations, and to force the adoption of safety appliances, but so far as the actual lowering of rates, when the railways have opposed them, their efforts have been a total failure.

They have harried our railways into bankruptcy, or nearly so, and as a net result, railway rates must be increased or the railways must go out of business or pass into the hands of the Government.

They have not seriously affected the principle that any rate must be what the traffic will bear. This principle survives. The correct policy is, by means of competition to make the traffic bear a less rate.

This competition such a system of connected waterways will give, and will, in its effect, be constructive and not destructive. By building up industries, and increasing population and prosperity, it will, in a greater and steadier freight movement, more than make up to the railways for the lower rates that will be enforced. And if this should prevent or even postpone the acquisition of our railways and their operation by the Government, with all the manifold evils that will follow therefrom, it will have paid for itself many times over and will be a truly economical development.

BIBLIOGRAPHY.

The detailed reports of the Special Boards of Engineers on the various sections of the Intracoastal Waterway, together with detail maps, estimates, etc., will be found in the following documents of the Congress of the United States.

Boston, Mass., to Beaufort, North Carolina, Section—House of Representatives Doc. No. 391, 62nd Congress, 2nd Session.

Beaufort, N. C., to Key West, Florida, Section—House of Representatives Doc. No. 229, 63rd Congress, 1st Session.

St. George's Sound, Florida, to the Rio Grande, Section—House of Representatives Doc. No. 610, 63rd Congress, 2nd Session.

DISCUSSION

Col. Townsend.

Col. C. McD. Townsend,* M. Am. Soc. C. E. (by letter), states that the Intracoastal Waterway described by the author, varying in width from 200 ft. to 40 ft. and in depth from 25 ft. to 5 ft. is illogical as a transportation route for through freight and has not received official

* Corps of Engineers, U. S. Army, St. Louis, Mo.

Col. Townsend.

sanction. The sections which have been approved are intended solely for local traffic. The channels 40 ft. by 5 ft. are to connect deeper waterways and to penetrate a region poorly supplied with railways where there is considerable local traffic, and will enable a motor-boat and barge to compete with a truck drawn by a team of horses on a country road in handling local products to the nearest port; as a means of competing with an ocean vessel or a first-class railroad, such a waterway would be a failure.

The cheapest transportation in the world is afforded by large ocean steamships. Tramp steamers of less than 30-foot draft can carry 10,000 tons of freight long distances for three tenths of a mill per ton-mile. On the Great Lakes approximately as good results are obtained by a vessel carrying 10,000 tons on a 20-foot draft, and on the Mississippi River coal tows transporting 48,000 tons on 8½-foot draft also are nearly as economical. However, for such tows wide channels are necessary to compensate for lack of depth, the minimum width necessary on the Mississippi River being 250 feet. With wide channels, economic results also can be obtained with depths of 5 feet. Logs and lumber formerly were rafted downstream on the upper Mississippi River for six-tenths of a mill per ton-mile, but the material was collected in rafts 100 ft. by 1000 ft. and 3 feet deep.

In a channel 40 feet wide the width of the tow must be limited to about 17 feet to permit two tows to pass, and one towboat can tow only two small barges with a carrying capacity for the fleet of possibly 450 tons of freight.

A simple analysis shows the impossibility of traffic in a narrow channel competing with the other methods of transportation described above. The ocean vessel has a crew of 36 men and moves at the rate of 15 miles per hour; the lake-freighter has a crew of 27 men and a speed of 12 miles; the Mississippi tow, 70 men and a speed downstream of over 4 miles. A boat engaged in through traffic on the Intracoastal Canal would require a double crew, consisting of a captain, mate, two pilots, 2 engineers, 3 stokers, three deck-hands and a cook. As the boat would displace over 33% of the area of the canal, its speed would be limited to 4 miles per hour. Therefore 13 men would be employed in moving 450 tons 96 miles per day, while on the ocean 36 men would have moved 10,000 tons 360 miles, or about 30 times as much would be required per ton-mile on the canal as on the ocean. A Mississippi River packet expends about 38 times the coal per ton-mile in transporting 325 tons of freight as a lake-freighter carrying 10,000 tons and, since it displaces less than 1% of the river's cross-section, it has a speed of about 12 miles per hour. Reducing to a speed of 4 miles per hour in the contracted channel of the canal, the coal expenditure of the same boat in the canal would be over 100 times per ton-mile that of the ocean vessel. The cost of the river carrier given as $12 per ton of freight by the special Board of Engineers on the survey of the Mississippi River, was obtained

Col. Townsend. by distributing the cost of the steamboat over 10,000 tons. When distributed over 450 tons, it would be many times greater. Also, it is a mistake to assume that insurance rates on inland waters are less than on the ocean; the insurance rates on the Mississippi River exceed 10% and are so prohibitive that few vessels are insured.

Colonel Townsend refers to an address delivered before the Commercial Club of Davenport, Iowa, March 11, 1914, in which Mr. Sterling Morton of Chicago described some experiments made by him in transporting salt from Chicago to Davenport over the Illinois and Michigan Canal and the Illinois and Mississippi Canal. The size of the load was limited by the dimensions of the Illinois and Michigan Canal (practically the dimensions of the proposed Texas Canals) and the total cost of delivering salt at Davenport is estimated at 6.5 mills per ton-mile. If salt were being delivered at Davenport in sufficient quantities to warrant its being shipped in trains of 1500 tons capacity, the salt could be carried on trains at a cost per ton-mile for labor and fuel of only about one-tenth that of the towboat. The total cost by railroad, however, would have to include the fixed charges on the original cost of the road and the maintenance charges and taxes, all of which are overhead charges from which the steamboat on a waterway built by the United States is exempt. In a thinly settled country where the traffic is so light that it is necessary for the railroad to charge about one cent per ton-mile or go into bankruptcy from those overhead charges, the canal possibly may compete as a freight carrier; but in the thickly settled portions of New York, New Jersey, Pennsylvania and Ohio, where there is dense traffic in coal, iron ore, grain and other materials, the railroads now charge only from 3 to 4 mills per ton-mile and pay dividends, and the small canal practically has been driven out of existence.

Mr. Morton calls attention to the fact that if the Illinois and Michigan Canal be enlarged to the dimensions of the Illinois and Mississippi Canal (7 ft. depth), the cargo to be towed can be increased to 1780 tons and the cost of transportation reduced to 2.5 mills per ton-mile. In the 25 ft. deep waterway proposed between New York and Philadelphia, a steamer and two barges could transport 10,000 tons of freight and the cost could be reduced to one mill per ton-mile.

Colonel Townsend states that if serious consideration ever be given to an intracoastal canal as a means of through navigation, a special study will be required to determine the proper type of boat and the economic dimensions of the canal for such types, as the boat must move over portions of the distance in restricted channels, while in others (Long Island Sound, Delaware and Chesapeake Bays, Pamlico and Albermarle Sounds and numerous wide stretches of water along the Gulf Coast), it will be exposed during storms to heavy wave action and should combine some of the qualities of a lake-freighter with those of a canal boat. The Mississippi River barge has not sufficient free-board to enable it to be towed safely through exposed waters.

For a proper elaboration of the subject of traffic on shallow waterways, and particularly for a fuller description of the comparative fuel expenditures by boat and by locomotive, Colonel Townsend refers to a paper by himself on the "Utilization of the Navigation of Large but Shallow Rivers", published in the Proceedings of the XII International Congress of Navigation, Philadelphia, 1912. Col. Townsend.

Mr. J. L. Jacobs,* Assoc. M. Am. Soc. C. E., said that the importance of intracoastal canals is not fully appreciated by many, especially by people in the interior of the country. In Louisiana and Texas there are large areas of rich agricultural land without adequate transportation facilities by rail, or by water except by means of small power-boats. Apparently there is but little hope of improving railroad transportation facilities in the near future. There are large agricultural developments and the products are transported to the markets by small boats, the most popular form being a small barge with a gasoline engine and covered by a tarpaulin. Such barges handle a great quantity of material at a very low cost. Improved waterways would give a great impetus to the agricultural development of this region. Mr. Jacobs.

The development of the iron industry in East Texas is dependent upon an adequate fuel supply, which can be obtained from the coal-fields of Alabama if cheap transportation becomes available. A project for developing the iron-ore deposits of East Texas by means of Alabama coal already has been financed and probably will materialize within the next 12 or 15 months.

Lt.-Col. C. S. Riché, in closing this paper, calls attention to the apparently overlooked fact that the cost of transporting freight by rail and the charge to the public for such service are two separate and distinct things, between which there is not, and in the opinion of the writer never will be, any fixed relation. Lt.-Col. Riché.

While agreeing fully with Colonel Townsend's views as to the desirability of a larger section for canals of this character, his view that the present small section is void of economic effect cannot be shared. To show that such a canal actually does compete with other means of transportation, the Intracoastal Canal between Galveston and Corpus Christi, Texas, may be cited. This canal, while dredged 5 feet deep and 40 feet wide, has never as yet had this depth throughout this entire distance of 202 miles. There have always been places where shoals have formed that have limited the through depth, so that for commercial purposes but three to three and one-half feet have so far been all that could be counted upon for through business. Nevertheless, the traffic on this part of the Inland Waterway, while still small, has been steadily increasing. For about a year a self-propelling barge of the Bernhard type has been operating in this section of the waterway between Galveston and Corpus Christi and is generally understood to be making money. This barge, while only running 13 hours per day with a single crew consisting of

* Mgr., James Stewart & Co., Inc., Houston, Tex.

Lt.-Col. Riché. one captain, one engineer, two deckhands, and one cook, carries less than half the double crew considered necessary by Colonel Townsend.

To show the saving in charges by this barge over railroad charges between these two points, the following special instances are given for some of the principal items of freight carried by the barge, all rates being in cents per hundred pounds.

Articles	Barge Rate	Railroad Rate
Cotton	20c	38c*
Canned goods	20c	30c
Galvanized sheet iron...........	19c	29c
Nails and pipe	17c	25c

In view of the above, a five-foot by forty-foot canal can hardly be said to be without competitive value to the general public, although confessedly a canal with larger cross-section would be of far greater value. It is to be noted that large ocean steamships cannot come to Corpus Christi, nor to other points along the line of this Inland Waterway, to which barges of this type have easy access.

In this connection it is worthy of note that the rate on lumber from Lake Charles, La., to Galveston, Tex., was 8¾c per hundred pounds until 1900. At that time this rate was lowered to 6c and the little schooners that had been carrying lumber from Lake Charles to Galveston via the Gulf of Mexico soon went out of business. About August, 1914, this lumber rate was raised to 10 cents and the question of again employing Gulf schooners is being considered. If today, however, an inland canal no larger than 5 feet deep by 40 feet wide existed between Lake Charles and Galveston (133 miles by proposed route for inland waterway), it is clear from the rates now charged by barge between Galveston and Corpus Christi that a lumber rate of not over 6 cents per hundred pounds could be applied by barge between Lake Charles and Galveston, and with a larger canal a still lower rate manifestly would obtain. Lake Charles originates a large lumber tonnage. It is not accessible to large ocean steamships.

This is a typical case, and it is the wide existence of such conditions, and the apparent helplessness of the people to cure them, that underlie the large, sincere and growing sentiment among the people for a development of our waterways and the linking of them together into a connected system, with the hope eventually of having adequate dimensions adopted and made standard.

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* The railroad rate is 51c, but this includes insurance and compressing charges, which amount to about 13c, so that on the same basis as on barge rate the railroad rate would be about 38c.

Paper No. 27

THE WATERWAY FROM THE GERMAN RHINE THROUGH THE NETHERLANDS TO THE NORTH SEA ALONG THE RIVERS RHINE, WAAL AND NIEUWE MAAS.

By

C. A. JOLLES, c. i.
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The Rhine, that takes its rise in the Swiss Alps and beyond Bodensee, or the Lake of Constance, winds its course for 150 km. along the frontiers of Switzerland and Baden, continues its way in a northerly direction after Basel, till it reaches the frontier between Prussia and the Netherlands, 690 km. below Basel.

Arrived in these "low countries", the Rhine, whose first part in the Netherlands is called the Upper Rhine, soon divides into three branches, of which the smallest, the Yssel, runs northward, emptying into the Zuiderzee; the two others, called the Lower Rhine and the Waal, continue in a westerly direction towards the North Sea. At this division, one ninth of the water flows down the Yssel, about two ninths along the Lower Rhine and about six ninths along the Waal. The Upper Rhine has a length of 10 km., the Yssel of 127 km., the Lower Rhine and its continuation, the Lek, of 121 km., and the Waal of 84 km.

Near the town of Gorinchem, the continuation of the Waal is called the Upper Merwede, which is 9 km. long and divides into two branches: first, the New Merwede, 20 km. long, which reaches the Hollandsch Diep near the village of Moerdijk; and second, the Beneden Merwede, 15 km. long, leading to Dordrecht. From Dordrecht, one branch, the Dordtsche Kil,

9 km. long, leads southward and flows also into the Hollandsch Diep; another branch, the Oude Maas, 30 km. long, runs into the North Sea off Brielle; while the third, the Noord, flows northward over a length of 9 km. The Noord joins the Lek off Krimpen; together, under the names of Nieuwe Maas, Scheur and Piercing of the "Hoek van Holland", they measure 44 km., and flowing past Rotterdam, empty into the North Sea. This route, from Krimpen to the North Sea, is also known as the "Waterway by Rotterdam to the Sea".

These different branches of the Rhine are to be found on the annexed map, Plate I.

The Upper Rhine, the Waal, the Boven Merwede, and the Nieuwe Merwede are of special importance by reason of their discharge of the water; the Upper Rhine, the Waal, the Boven Merwede, the Beneden Merwede, the Noord, and the "Waterway by Rotterdam to the Sea" for the Rhine navigation. The older branches have also their share of navigation, but on the whole they rather serve local interests; yet the Yssel has plenty of shipping for the northern provinces and when the water is high enough, the Rhine boats for Amsterdam follow the Lower Rhine, the Lek and thence the Merwede Canal from Vreeswijk to Amsterdam. For the Rhine navigation from Germany to the North Sea, the principal route is the one down the Waal and the Noord to Rotterdam.

Whereas at first the Rhine gets its water only from various mountain streams in the Swiss Alps, lower down it gets considerable quantities of water from important tributaries, such as the Neckar, the Main, the Moselle and several smaller ones. So the Rhine is fed not only by the glacier and snow water of the Alps, but also by the rains falling on other mountain chains and plains. This circumstance is of the greatest importance for navigation, as the periods of drought in the sources of the Rhine hardly ever coincide with those of the tributaries, so there is usually water enough in the Rhine to ensure regular navigation.

The maximum discharge of the Rhine at the highest known stages of the river amounts to about 6000 cu. m. per second at Basel and to about 10,000 cu. m. per second near the Netherland frontier. At the lowest known stages, the discharge of

the Rhine near the Netherland frontier amounts to nearly 1000 cu. m. per second. At Basel the water flows at a rate of about 3 m. per second; in Holland under normal conditions at a rate of less than 1 m. per second.

Already in the remotest periods we read of the Rhine as being an important route of navigation in the remote periods. The Romans, when extending their empire as far as the shores of the North Sea at the beginning of our era, found in the navigability of the Rhine an excellent help in transporting troops and materials; so they erected several fortified places along the stream, out of which arose towns like Mayence, Bonn, Cologne, and others. By building these fortresses on the left bank, they utilised the Rhine, at the same time, as a barrier against the Germans, whose territory lay beyond the right bank.

To meet modern requirements, the Rhine is navigable from the North Sea as far as Strassburg, that is, over a distance of 735 km. No river in the world is so well suited for navigation, and on none has that navigation caused as much prosperity throughout the ages as on the Rhine. This is the reason why efforts are continually being made to render the stretches of the Rhine above Strassburg navigable, and to study its navigability from Basel upstream to the Lake of Constance. For several years a service of tugboats has been organised between Strassburg and Basel. Should all those plans succeed, then the waterway fit for navigation will have a length of 1080 km. (nearly 600 miles), from the "Hoek van Holland" on the North Sea to Bregenz on the Lake of Constance.

As the greater part of the goods shipped on the Rhine boats comes from across the sea, or is to be transported across the ocean, the importance of the traffic increases toward the lower part of the river; indeed, the greatest traffic is found between Rotterdam and the ports on the river Ruhr, on a length of the Rhine of 250 km. Higher up, we find the important ports of Dusseldorf and Cologne; the principal town on the Upper Rhine being Mannheim, in the north of Baden.

The governments interested in the navigation on the Rhine have always taken great pains to ensure favourable conditions for that waterway. The international importance of the Rhine,

not only for the countries along its banks, but also for more remote parts of the world, was already realized at the Congress of Vienna in 1815, which, after the fall of Napoleon, regulated many questions of great interest for Europe. It was decided there that navigation on the Rhine should be free for every one, and the congress placed the river under the joint supervision of the states along its banks so far as the interests of traffic with vessels and rafts were concerned. These principles formed the foundation of the Rhine Navigation Treaty, originally named the Convention of Mayence, of 1831. In 1868, this treaty was revised; one of the most important changes was that no longer should toll be levied on navigation.

The whole "conventional" Rhine meant in those treaties, that is, the Rhine from Basel to Krimpen and Gorinchem (where the influence of the tide makes itself felt), is placed under the same police regulations for navigation. Those regulations are drawn up by the central Committee for the Rhine Navigation and sanctioned by the Rhine-states, who appoint the members of that Committee.

The amelioration of large rivers for navigation, as well as for the discharge of water and ice, has taught us, in the course of the 19th century, the advisability of giving a regular width to the summer bed of a river; such width being called normal width.

The great calamities caused by floods and ice, resulting in destruction of property and loss of life, especially in the lower countries, have finally taught that the amelioration of the channel itself is an excellent remedy in reducing such accidents in number and extent, perhaps, even in preventing them altogether. The need of such ameliorations was especially felt on the lower part of the Rhine, below Cologne where the river flows through level countries. Though this remedy may seem very simple, now that experience has proved its advisability, yet a long struggle was required to get its application decided upon.

In the Netherlands, a general amelioration of the rivers on those principles was begun in the middle of the 19th century. This work on the waterway from Germany to the North Sea can be divided into several periods.

In the first period, the islands lying in the river bed were connected on one side with the shore, while on the other side of them the remaining channel was widened.

In the second period, the summer bed, serving for the discharge of water in normal conditions, was reduced to its normal width by the construction of low parallel walls and groynes.

In the third period, an attempt was made to improve, by a partial narrowing of the river, such parts of the summer bed as did not yet come up to the standard.

In the fourth period, an attempt was made to give a more regular depth and direction to the channel, by a further normalizing and an improvement of the horizontal plan of the summer bed. On each of the different river branches which form the waterway from the German Rhine to the North Sea, in the Netherlands, those changes have been more or less effected.

At the treaty of October 7, 1816, which settled the frontier between Prussia and the Netherlands, the normal width of that part of the Upper Rhine which forms the frontier over a length of 7 km. was fixed at 565 m. When, in 1850, Prussia and the Netherlands began to normalize the Rhine, it soon appeared that this dimension was much too large to ensure an unaltered and practicable channel for water discharge and for navigation. So, in 1866, the normal width of that part of the river was fixed at 90 Rhineland yards, or 340 m.

The works required to narrow the summer bed were executed in the years 1868-1876. They have entirely come up to expectation; the remaining 3 km. of the Upper Rhine were reduced to the same width in 1899-1901, in connection with the earlier alteration.

In the meantime, the lengthy deliberations, which, in the Netherlands, preceded the work on the improvement of the rivers, had led, in 1861, to the fixing of a normal width for the summer bed of the Waal, of 360 m., gradually increasing to 400 m. lower down; of 600 m. for the Boven Merwede; 200 m. for the Beneden Merwede; 225 m. for the New Maas at Krimpen, and 450 m. at Vlaardingen. No normal width was fixed for the Noord.

The improvement of the Waal, on the principles mentioned above, was commenced about the middle of the 19th century.

The first period may be fixed at 1850-1875. During that time, several islands in the middle of the river were connected with one of the banks and dug off on the other side, and lower parallel walls or groynes were constructed below and above them. Also in several other places, the excessive width of the river was reduced by groynes or walls.

In the second period, 1875-1886, the whole length of the river was systematically reduced to its normal width by building groynes into the river. Next, an attempt was made to deepen the shallower parts of the channel by dredging.

In the third period, 1889-1896, the river was further narrowed in the bends of river-crossways and also in strong curves by low mattress-works; the channel was again improved by dredging, which was extensively continued in the years between 1897 and 1906. When all this did not give the expected results, the normal width was reduced to 260 m., in 1909-1914; at the same time, some of the works were removed, which altered the course of the normal channel in such a way that now it is shut in by curved lines only, so that there is not a single straight section left in the river. These latter improvements were executed without dredging; it was attempted to obtain and preserve a serviceable channel rather by directing the current into a certain direction. The works executed in those years are shown on Map II, which gives the various developments in one section of the river, near the town of Tiel.

Under the writer's approval, this map has been copied chiefly from the report of the Engineer, Mr. Baucke, for the first section of the XIIth International Navigation Congress at Philadelphia in 1912. The works made in the river for these improvements all consist of osier matting (mattress-works) filled up with sand and the whole steadied with stone, mostly basalt from the mountains along the German Rhine. There is plenty of osier in the Netherlands. The improved system of dredging machines made it gradually possible to throw more and more sand into the mattress-works, so that the osier matting and stone were only needed for the outer cover, which greatly reduced the cost.

The groynes were usually made so high that on the river side they rose 0.50 m. above M. R. (the average summer water-

level) with a landward slope from 100 to 200 to 1. The lower works, constructed in the third period, were not made higher than 3 m. below M. R., because they were placed in the normal summer bed. The groynes made in the fourth period were kept about 1 m. lower than the existing ones, lest the important reduction of the former normal width should alter the profile too much.

The cost of the above-mentioned ameliorations of the river Waal, during the years 1850-1914, amount to, roughly, 17 million guilders.

The Boven-Merwede, which extends from Woudrichem to Hardinxveld, has been normalised in the same way as the Waal.

The first works were begun in 1863, and in 1899 to 1906, low groynes were made to narrow the river still further. In this way, the normal width of the Boven Merwede was reduced to 450 m. for the upper part, and to 500 m. for the lower part in the years 1890 to 1896. As especially the upper part of the channel remained unfavourable, the work of the fourth period, in 1910, comprised the turning of the normal summer bed southward, in order to give the necessary curve to this nearly straight section of the Boven-Merwede. This was accompanied by a further narrowing of the normal width, all the way down the Boven-Merwede, to 350 m. for the upper part and 450 m. for the lower part. This work will be ready in 1914.

The cost of all these improvements of the Boven Merwede may be estimated at 3½ million guilders.

The improvements on the Beneden-Merwede were, on the whole, of a simpler kind; they were made between 1850 and 1885, and cost about two-thirds million guilders.

Neither did the improvements on the Noord between 1867 and 1901 lead to any considerable expense; it amounted to one-half million guilders. This section of the river is, however, too narrow for the ever increasing traffic, so that a widening to 200 m.—the cost of which is estimated at 1¾ million guilders—must shortly take place. The Noord is now from 100 to 150 m. wide.

The rivers Beneden Merwede and Noord do not serve greatly for the discharge of water, so they do not get such a

large deposit of sand from the higher sections of the river as some of the other rivers. Hence, no special care is required to keep them at their normal depth; this is attained by some simple dredging operations.

The work on the remaining parts of the river, Nieuwe Maas by Rotterdam to the sea, is of quite a different kind, because the improvements on this section of the river implied the formation of a new fairway from Rotterdam to the North Sea. The natural outlet of the Nieuwe Maas from Rotterdam, by Brielle, had become practically useless for navigation at the beginning of the 19th century, because it had become too shallow. So, for the benefit of Rotterdam's trade, a ship canal was made in the first part of the 19th century from Nieuwesluis to Hellevoetsluis, uniting the Nieuwe Maas and the Hollandsch Diep, the locks being able to accommodate vessels having a length of 70 m., a breadth of 13.50 m. and a draught of 55 m.

When, about the middle of the 19th century, this waterway in its turn proved insufficient for the requirements of modern traffic, the Engineer, Mr. P. Caland, proposed to construct a new open outlet to the sea by cutting through the dunes of the Hoek van Holland and by normalising the river between Krimpen and this canal. Mr. Caland thought this the way to obtain a waterway, which would come up to all the requirements of traffic, and where the alterations of ebb and flood would keep the channel in a favourable condition.

The work was begun in 1866. Though the cost was considerably higher than what was at first estimated, yet the results have far surpassed the expectations, and a waterway has been constructed which has contributed to the enormous development of Rotterdam as a harbour town.

According to the plan of Caland, the Nieuwe Maas was to have at Krimpen a normal width of 225 m., which increases to 450 m. at Vlaardingen, and to 900 m. at the Hoek van Holland. This normal width was obtained in about the same way as is explained above for the Waal.

To begin with, the islands in the river were connected with one of the banks, so that the movements of the tides were concentrated in one channel. Next, the river was reduced to one

normal width by the construction of groynes and lower parallel walls on one hand and by digging off the banks on the other hand. In the meantime, the work on the canal through the dunes advanced quickly, while two breakwaters, each projecting about 2 km. into the sea, lengthened out the river till it reached deeper water.

The work of cutting through the dunes consisted at first only in making one very narrow channel. It was expected that the tide would gradually widen and deepen this channel, which would have meant a great reduction of cost. The results were what had been expected, but the sand, swept away in this fashion, accumulated between the breakwaters, where it could only be removed with great difficulty. A further study brought about a revision of the plan in this sense, that, though the old principles would be adhered to, the formation of the outlet through the dunes would not be chiefly left to the tide, but would be performed by machinery. Because of the great expense caused by this way of proceeding, other dimensions, mostly smaller ones, were adopted for the river, viz., 250 m. at Krimpen, 340 m. at Rotterdam, 450 m. at Vlaardingen, 530 m. at Maassluis and 700 m. at the sea-mouth. Between the two breakwaters, therefore, a new one was added 200 m. from the southern one.

An energetic resumption of the work on these principles, and untiring labour all along the river, brought the expected results towards the end of the 19th century.

In the meantime, the requirements of traffic had considerably increased, chiefly on the point of depth. Whereas, about the middle of the 19th century, 6.5 m. below low tide, corresponding to about 8 m. at high tide, had been considered more than sufficient, at the end of that century it was evident that for a harbour of international importance, such as Rotterdam had become in the mean time, that depth was not great enough. So it appeared necessary to improve the waterway still further. The means employed were those applied to the Waal in the third period, that is, by altering its profile by low groynes, which would give greater depth to the channel.

Especially the lower part of the Rotterdam waterway appeared in need of those improvements. On the upper part, the

fairly regular bends in the river contribute to the formation and preservation of a channel with uniform depth. Probably this lower part will have to be altered in the way described for the Waal in the fourth period before the favourable results obtained on the upper part can be obtained and made permanent in the lower part also. Yet a great part of the success of the New Waterway has to be ascribed to the powerful dredging operations continually carried on in the river and in the river mouth. A greater depth of the channel will be obtained by the same means, though, according to the principle of the designer of these works, the greater depth will again be maintained mainly by the well-directed tidal currents. In order to regulate the inflow of high-tidal currents, a jetty is in course of construction on the sea end of the south breakwater, which will, at the same time, enhance the safety of entering vessels.

The cost of the construction and the improvements of the Rotterdam Waterway on the above mentioned principles amounted, up to the end of 1913, to over 55 million guilders.

Though originally the many calamities caused by inundations and drifts of ice led to the improvements on the Netherland rivers, which were planned at the beginning of the 19th century and executed after the middle of that century, yet the need of a better route for navigation had also made itself felt.

The numerous shoals in the rivers and the fitful course of the channel led to the formation of new shoals and to accumulations of ice. They were also an impediment to navigation.

Long ago, the scale of the water-level at Cologne was used as a standard to measure the depth of the river channel of the route for Rhine traffic in the Netherlands, and even now this standard is generally used for the different river branches in that country. About the middle of the 19th century, the average depth of the channel of the Netherlands Upper Rhine and the Waal was so small that those rivers were practically useless for navigation, as soon as the water was at all low. Below Gorinchem, things were not much better, but there the influence of the tides at least made navigation possible at high tide.

The Rhine Navigation Treaty, mentioned previously, which was drawn up to further the common interests of the states

along the Rhine, had not only charged a Central Committee with the care of these interests, but also decided that a joint inspection by the different river engineers, should periodically take place of the whole Rhine below Basel, in order to judge of the condition of the river as a fairway.

The first voyage of inspection, according to this regulation, took place in 1849. Of course it served especially to get acquainted with conditions in the different sections; as yet, it could not lead to discussions about changes to be made.

The second voyage of inspection, in 1861, led to more fundamental and extensive discussions, an important point of which was the uniform depth of the channel. As a standard, the water scale at Cologne was adopted, on which the zero probably formerly indicated the bottom of the river.

It was then thought desirable to have the bottom 1½ m. lower than it would have been in earlier times; in connection with this, the Rhine from Cologne to the sea was also to get that depth. This plan was thought feasible, because the bottom of the river over the whole of that section consists of shifting sand. Only at one spot, in Germany below Cologne, is the bottom rocky, but this could easily be removed.

The state of the river bottom above Cologne would make a depth of ½ to 1 m. less than below Cologne acceptable there.

So a depth of 1½ m. below zero of the scale at Cologne would correspond with a depth of 3 m. at normal low-water level (1.50 m. by Cologne water mark).

According to observations extending over several decades, the level of the water hardly ever sank below 1.50 m. at Cologne; on an average during only ten days per year, exclusive of periods when the shipping was stopped by drifts of ice. For the water-level on the Netherlands rivers compared with Cologne, it was supposed, in 1861, that 1.50 m. on the scale at Cologne should correspond with M. R. on the Netherlands rivers. M. R. means the average summer level, according to daily observations during the summer months (1st of April to 30th of September). This supposition was without any doubt too favourable, as it was already evident that the low mark of 1.50 m. at Cologne corresponded with a level below the average summer level on the Netherlands rivers.

The following voyage of inspection, in 1874, saw this point more closely considered; and in 1885, it was definitely settled, by calculating the level noted on various scales on the Netherlands river branches at different periods, when the level at Cologne was about 1.50 m.

Though the governments of the Rhine states have not entered into any agreement on that subject, yet the object of the amelioration of the waterway on the Rhine from Cologne to the North Sea (Upper Rhine, Waal, Merwede, etc.) has been accepted as a channel wide enough for navigation and with a minimum depth of 3 m., or a level of 1.50 m. at Cologne. For the other branches of the Rhine (Lower Rhine and Lek), by common accord, a minimum depth of 2 m. was thought sufficient under those circumstances.

When the work of normalising the river was begun, the principal waterway lacked more than a meter in depth, but what made the channel, at any low water, especially unfit for navigation was its irregular form—the numerous windings from one side of the river to the other and the sharp turns in the line connecting the deepest parts (the fairway). Moreover, the shifting sands made it necessary to alter the channel continually.

It could be truly said that in the first half of the 19th century the Waal and the Merwede had run wild; the measures taken to alter the river succeeded only slowly in replacing that chaos by some order and regularity. The normalizing, begun systematically in 1875, brought about some improvement, but as late as in 1888, 14% of the length of the Waal still lacked the hoped-for depth of 3 m., and the channel still contained many inconvenient bends. The further normalisation, begun in 1888, brought some more improvements, but the depth and the direction of the channel were not yet constant.

It became more and more evident that the normal width had to be reduced and that the form of the river bed should be altered in such a way that the straight sections, where the channel had been especially changeable of direction, should disappear, and that the different bends should become of equal importance, if possible. This last normalisation of the Waal has led to a complete success, and the experience gathered dur-

ing these laborious improvements guarantees a lasting effect, provided the different riverworks are kept in good condition, which need not cost much.

On the Merwede, the Boven and Beneden Merwede, as was already mentioned above in a few words, the navigation has never experienced such great difficulties from the shallowness of the channel, because the tides made it possible to get across the shallow parts at high water. The difference between ebb and flood is about 0.80 m. at Gorinchem; about double that difference is found at Dordrecht. Yet the excessive width, originally 600 m., has caused difficulties, especially on the straight upper part of the Boven Merwede. These difficulties are of depth as well as of direction of the channel. It is expected, however, that the reduction in normal width, which is nearly completed now, and the simultaneous alteration in form of the upper part of that river will also, in the long run, give a depth of 3 m. at ebb-tide with a channel of sufficient width and practical form, and that those favourable conditions will be maintained. At the end of 1913, this depth had been obtained over the whole length of the river, but the channel was not yet everywhere wide enough.

On the Beneden Merwede and the Noord, a depth of 3 m., even at low tide, may be relied upon; the channel is in all respects suited for Rhine navigation, though the Noord becomes too narrow for the very crowded traffic on that part of the waterway.

On the Nieuwe Maas from the Noord to Rotterdam, the depth of the river is over its whole length, practically, several meters greater than Rhine navigation requires. This superior depth is maintained in connection with the fact that the waterway by Rotterdam to the North Sea is a tidal river, so that a permanently wide and deep channel is required above Rotterdam in order to strengthen the movements of the tides.

The design, made about 1860, of a new waterway from Rotterdam to the sea through the Hoek van Holland, was intended to form a channel of sufficient width for all ocean vessels, with a minimum depth of 6½ m. at low tide. As the difference between high and low tide is 1.40 m. at Rotterdam and 1.50 m. at Hoek van Holland, the minimum depth of the chan-

nel at high water would be about 8 m. This result was obtained about 1895 by the works briefly described previously.

In the meantime, a depth considered amply sufficient for all traffic in the middle of the 19th century had become insufficient when it was obtained, after a labour of 30 years, owing to the ever increasing size of ocean vessels. So the work of making the waterway deeper was steadily continued, with the result that, in 1905, the permanent channel had a minimum depth of 7½ m. at low tide, which, in 1912, had increased to about 8½ m. at low tide. This corresponds to 10 m. at the average high water. Even the 8½ m. below low tide can easily be maintained by the powerful tidal currents, though it requires some dredging, especially on the lower part of the river, where the normal river bed presents hardly any curves. But even now improvements have to be continued; probably the channel between Rotterdam and the North Sea will be made 1½ to 2 m. deeper, by dredging, within a few years, so that a permanent depth of about 12 m. at high tide will be obtained. The mouth of the waterway at the Hoek van Holland has already a depth of about 11 m. at high tide over a length of nearly 3 km. It is doubtful whether a depth of 3 m. at normal low water level (1.50 m. at Cologne) will in the long run be sufficient for the Rhine navigation between Cologne and Rotterdam.

The calculations made before 1861 had shown that the level of the water fell below that mark only during ten days a year; but in 1885, in consequence of the improvements of the channel, this number had increased to 25 days per year, and in 1908, to 72 days on which the level did not reach 1.50 m. at Cologne. So, on all those days, the channel below Cologne would have had a depth of less than 3 m. If the former condition, that the average depth of 3 m. may not be found lacking on more than ten days a year, should be maintained, then we come to an average level of 1.20 m. or, perhaps, even 1 m. at Cologne, so that many parts will have to be made deeper. Probably the work of making the channel deeper would not cause great difficulty for the part in the Netherlands.

Special care is bestowed on marking the channel with buoys in the rivers of the Netherlands.

The limits of the channel are indicated by buoys fastened by means of anchors or heavy stones; those on the right hand side downstream of the channel are black, square-topped buoys, those on the left hand side are red and pointed. Moreover, beacons are placed on the banks, the tops of which are baskets painted in the national colours (red, white, blue). The baskets indicate the direction of the channel, two of these beacons of unequal size, the smaller one in front, being placed on the bank. If only one beacon of that form is seen, then the channel is to be found on that side of the river. On the waterway below Rotterdam, buoys are used in the same way; but the basket beacons are replaced by beacons with a light at the top, so that navigation can continue at night.

The supervision of the buoys and beacons on the river above Rotterdam is entrusted to beacon masters, who each look after a river-section of about 8 km. in length, and who, when required, have to pilot the vessels. On the waterway below Rotterdam, this work is done by the department of pilotage, which also settles the cost of pilotage. The pilotage is compulsory, and the cost depends upon the draught of the vessel.

The winding course of the channel in the Netherland rivers makes a system of beaconage indispensable, especially where the normalizing of the rivers is not far enough advanced to give permanency to their channel. While the works of normalisation on the Waal were in progress, the beacon-masters had to displace the beacons nearly every week, because the direction of the channel was continually changing. The alterations now in progress, those of the fourth period, have brought more stability in this respect; neither does the channel pass so often from one bank to the other.

Whereas in 1906 on the lower part of the Waal, over a length of 44 km., the channel passed 42 times from one bank to the other, this happens now in only 20 places, which number will be further reduced when the effects of the last normalisation have made themselves felt for some years. In the end, the channel will have to follow the bends of the river and will be found in about the middle of the river, with a slight deviation towards the inside of the curves.

As the Rhine has always been a fairway of great importance, it is only natural that navigation has profited by all the improvements of the channel, and that the development of the traffic on the river corresponds with those alterations. Wherever the Rhine, especially the lower part, was improved in the latter part of the 19th century and in the beginning of the 20th so as to meet the requirements of navigation, traffic was enormously increased. The development of industry in Germany and the Netherlands has also contributed to this traffic, as well as the extraordinary increase of ocean traffic, which is closely connected with Rhine traffic.

The latter leads to three important commercial towns: Amsterdam and Rotterdam in the Netherlands, and Antwerp in Belgium. Goods for the Rhine are trans-shipped in those ports from the ocean vessel into the Rhine ship and vice versa. Besides, the last twenty years have seen a number of ocean steamers plying between Hamburg, London, Bremen, Stettin, Copenhagen, Kiel, Lübeck, Riga and other ports on the Baltic on one hand, and the Rhine on the other. The number of those steamers amounts already to more than 60, their tonnage to 22,000 tons net. These steamers run once a week, once a fortnight, or once a month between the above-mentioned seaports, and between those ports and Cologne, Dusseldorf and Ruhrort. As the channel of the Rhine below Cologne has an average depth of about 3 m. at low water, those steamers can navigate the Rhine above Rotterdam generally only when partly laden. In 1912, more than 650 of these vessels passed the frontier between the Netherlands and Germany, with a tonnage of 115,396 tons, of 1 cu. m., upstream and 137,830 tons downstream; together making 253,226 tons.

Besides these ocean steamers, the Rhine below Cologne carries about 50 sea-lighters from the Baltic, Hamburg, etc., with a carrying capacity of 500 to 1000 tons each; and about 80 sea-going vessels, which go up the Rhine to the harbours on the Ruhr, to Dusseldorf, Cologne and Remagen, and, sometimes, as far as Oberlahnstein. These vessels have a draught of 2 to 2½ m.

In 1875, the number of Rhine vessels from and to Amsterdam and Antwerp amounted to 17,577, with a carrying capacity

of 2,472,000 tons of 1000 kg. (which kind of ton will be meant for all further statistics of Rhine navigation). In 1885, the number of vessels had increased to 29,486 with 4,495,000 tons; in 1895, to 40,367 with 7,928,000 tons; in 1905, to 71,782 vessels with 20,651,000 tons of cargo.

The principal articles carried upstream are ore, corn, wood, paraffine and English coal; those carried downstream are German coal, gravel, cement, raw iron, rails, stone, coal-bricks, coke, etc.

The total traffic across the frontier of the Netherlands and Germany, upstream and downstream, in 1912, amounted to 91,000 vessels, with a cargo of 34,615,000 tons. Of these vessels, 64% flew the Netherland flag, 22% the German, and 14% the Belgian flag.

Of the goods carried upstream in 1913 (19,814,000 tons in all):

557,000	tons	came	from	Amsterdam
15,740,000	"	"	"	Rotterdam
400,000	"	"	"	other Netherland ports
2,893,000	"	"	"	Belgian ports
224,000	"	"	"	ports across the sea

17,715,000 tons were transported downstream:

975,000	tons	to	Amsterdam
7,024,000	"	"	Rotterdam
3,245,000	"	"	other Netherland ports
6,180,000	"	"	Belgian ports
290,000	"	"	ports across the sea.

So we see that the traffic to and from Rotterdam exceeds that to other places, though the traffic to Belgian ports is nearly equal to that to Rotterdam. There is little trade from other Netherland ports besides Amsterdam and Rotterdam; most of the trade under that head comes from Dordrecht, in the form of lime, wood, etc. The trade to other Netherland ports is more important, especially that in coal, stone, fertilizers, etc.

The enormous development of the Rhine navigation in the late decades is closely connected with the increase of traffic in the three above mentioned seaports, the most important of

which, as we see from the list of statistics, is Rotterdam. The amelioration of the Rotterdam Waterway is, of course, an important factor in this prosperity; other factors are the liberal way in which the Municipality of Rotterdam provides new harbours, and the splendid management and the fair tariff of harbour duties at that place.

When the improvements on the Rotterdam Waterway had begun and the Hoek van Holland had been pierced, though at first only in a small measure, the number of ships entering and leaving the waterway (fishing-boats excluded) amounted in 1873 to 4471 vessels carrying 1,321,000 tons (Moorson).

At the end of ten-year periods, these amounts were:

1883,	7,788	vessels	carrying	3,827,000	tons
1893,	9,628	"	"	7,220,000	"
1903,	15,802	"	"	15,322,000	"
1913,	22,645	"	"	27,831,000	"

So in every ten years, the tonnage has about doubled.

This development in water traffic has raised Rotterdam to the second place in the rank of seaports on the continent of Europe. Hamburg is the only port with more traffic than Rotterdam, and the latter place has become nearly the equal of Hamburg.

DISCUSSION

Col. Townsend. **Col. C. McD. Townsend,*** M. Am. Soc. C. E., said that a comparison between the Rhine and the Mississippi as waterways is interesting. The Mississippi River has a depth exceeding 30 feet as far upstream as Baton Rouge and is being improved so that it will have a depth of 10 feet at all stages as far upstream as Cairo, which is nearly 1000 miles above the mouth of the River. From Cairo to St. Louis the depth will be 8 feet at all stages. These depths are greater than those prevailing on the Rhine and nevertheless have been obtained with comparatively little expenditure. Suction dredges are able to maintain a 9-foot depth at Cairo with an annual expenditure of $500,000. Between Cairo and St. Louis the annual cost of dredging to maintain an 8-foot channel is $250,000. The dredge is a success in the maintenance of a permanent channel if funds are not available for a more expensive system.

The commerce carried by the Mississippi is much less than that of the Rhine, however. In 1883 the Rhine commerce amounted to 3,827,000 tons, while on the Mississippi the commerce passing St. Louis was about

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2,000,000 tons. In 1913 the commerce on the Rhine had increased to 27,831,000 tons, while the commerce of the Mississippi was 2,150,000 tons, or but slightly more than in 1883. These figures of commerce on the Mississippi do not include that coming down the Ohio River and entering the Mississippi at Cairo. Col. Townsend.

However, there is a waterway in the United States (that connecting Lake Superior and Lake Michigan) which does compare quite favorably in its commerce with the Rhine. In 1880 the commerce passing between these lakes amounted to 1,389,000 tons and in 1913 had increased to 79,000,000 tons. It is thus seen that in the United States there is a waterway quite as successful as a commerce carrier as any existing abroad, though this cannot be said of the Mississippi.

Up to 1890 Congress asserted that levee work for preventing overflow could not be paid for with money appropriated for improving navigation at low water, but in 1901 and 1902 the law was changed and since then levees, if beneficial to navigation, may be constructed from the funds appropriated for the Mississippi River; so in recent years large sums have been spent on the Mississippi River, chiefly in levee construction.

Prof. C. D. Marx,* President Am. Soc. C. E., said that it is notable that the Commission in charge of the improvement of the Rhine has full power not only to provide a suitable channel for low-water navigation, but also to do any other work necessary for the proper regulation of the Rhine, including the building of levees to prevent overflow. It is interesting to compare this method of improvement with that which formerly was the practice on the Mississippi River, where until recently the improvement of low-water navigation was the only object. Prof. Marx.

In the early eighties the method of improving the Mississippi River consisted largely of mattress construction for directing the current. From Colonel Townsend's discussion it is evident that the cost of improvement by dredging is far less than that by the old mattress construction.

During the eighties a large amount of freight came down the Mississippi River, including grain barges from St. Louis, and there was a general active river traffic between St. Louis and New Orleans. It is unfortunate that such traffic has decreased on the Mississippi River, but there is some encouragement to waterways in the fact that there are one or two places in the United States where their freight traffic is important.

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Paper No. 28

THE NATURAL WATERWAYS OF RUSSIA.

By

N. P. POUZIREVSKY
Petrograd, Russia

The extensive Russian Empire occupies approximately 42 percent of the area of the two continents of Europe and Asia, having a total area of about 22,500,000 square kilometers (8,687,000 sq. mi.). Of this amount, about 5,500,000 square kilometers (2,123,000 sq. mi.) are situated in European Russia, and 17,000,000 (6,564,000 sq. mi.) in Asiatic Russia.

These two portions of the Russian Empire are separated from each other by the Ural Mountain Range running in a general direction of from north to south, from the Arctic Ocean to the Oust Yourt plateau, which forms the watershed between the Caspian and Aral Seas.

The surface of European Russia has a level character, the central portion being slightly elevated—the highest portions being from 150 to 250 meters above the level of the Baltic Sea. From these elevated portions, forming watersheds, rivers flow northwards as well as southwards; the former flow in the direction of the Baltic and White Seas, and the latter to the Black and Caspian Seas. The watersheds have not the appearance of mountain ranges, but form flat elevations, with large portions covered with lakes and marshes, from which the rivers of European Russia take their sources.

In consequence of such a construction of surface, the sources, for example, of the principal rivers of European Russia (the Volga, Dnieper and Western Dwina) are very closely related, being situated on one and the same marshy plateau, as likewise are the sources of other smaller rivers. This circumstance makes it extremely convenient for connecting all the rivers of European Russia into one general network by means of the construction of connecting canals between them.

In consequence of the small elevation of the watersheds, in most instances the rivers of European Russia have small falls and low velocities of current, which are very favorable for their development as commercial highways.

The constant work of the currents of water has pulverized the large portions of the soil of the river beds and has given them valleys of very similar character, and therefore the slopes of greater portions of the rivers are uniform; of course it is not everywhere that such work of the current is completed, and there are some portions of the rivers of European Russia which consist of hard, rocky ground. At such places the rivers have great declivities and very swift velocities of current. The more important of these places are as follows: the Dnieper rapids, situated on the river Dnieper between the towns of Ekaterinoslav and Alexandrovsk, where in a distance of 102 kilometers (63.4 mi.) the fall amounts to 31 meters (101.7 ft.); the Volhovskie rapids, situated on the lower portion of the Volhov, at 20 kilometers (12.4 mi.) from the mouth, have a fall of 9 meters (29.5 ft.) in a distance of 9.8 kilometers (6.09 mi.); the river Narova has a fall of 30.9 meters (101.4 ft.) in a distance of 72.5 kilometers (45.0 mi.) of its length. About one-half of this fall takes places in 7 versts (4.64 mi.) of its course, at the town of Narva. The Imatra waterfalls have a fall of 19 meters (62.3 ft.) in a distance of 1 kilometer (0.62 mi.). They are situated on the river Vouoksie, which runs from the Saima Lake and flows into Lake Ladoga.

In European Russia there are also several rivers with comparatively large slopes, and therefore having currents of high velocities. Amongst these can be included the river Dniester, which has its source in Austria, in the Carpathian Mountains; the river Tschousovd, which flows along the European slope of the Ural Mountains; the river Msta, flowing from Lake Mstino at Vishni Volotchok and falling into Lake Ilmen, which has a length of 434 kilometers (270 mi.) and a fall of 132 meters (433 ft.). The greatest fall is at a portion of this river between the Opetschenskie settlement and the town of Borovitchi, where the current attains a velocity of 30 kilometers per hour (18.6 mi. per hr.). Such a velocity is not an unsurmountable obstacle for shipping traffic along the river, as a

considerable number of rafts and barges with hay are floated down the river Msta with the current.

In Asiatic Russia the surface of the land has a general slope to the north, commencing from the southern frontiers of the Empire, and the two principal rivers have their sources in the hills on the high table-lands outside the territory of the Empire, and intersect the whole of Asiatic Russia from the south to the north. These rivers are the following: the Obi, with its tributary, the Irtisch with the Om, having from the source of the Irtisch to the junction of the Obi with the sea a length of more than 5000 kilometers (3,100 mi.). The Yenesei, with a length of 4,750 kilometers (2,950 mi.), has its source in Mongolia at the junction of the two rivers Ouloukima and Hakima, and receives the large tributary Angara, which flows out of Lake Baikal, into which the river Selenga flows, which in turn has its source in the Altai Mountains. From the source of the Selenga to where the Yenesei flows into the Arctic Ocean is more than 5,000 kilometers (3,100 mi.).

The other rivers of Asiatic Russia follow the same general direction, some inclining towards the east and some towards the west, as, for instance, the Lena, which has a length of 3,400 kilometers (2,100 mi.), and commences at 30 kilometers (18.6 mi.) to the west of Lake Baikal.

The exceptions to the general rule are represented by the rivers of the basin of the Pacific Ocean, the principal of which is the Amur, the waters of which flow to the east, but having several of its tributaries flowing from north to south.

The surface of Asiatic Russia as compared with European Russia is extremely uneven, the elevated portions of it being situated at more than 1,000 meters (3,280 ft.) above the level of the sea; the northern portions of it are more depressed, and in many places are covered with marshes.

In the southwestern portion of Asiatic Russia there are deep valleys, the very lowest parts of which are filled with the waters of the Aral Lake, or more correctly the Aral Sea, which has a water level of about 48 meters (157 ft.) above the level of the ocean.

Into this sea flow the two large rivers, the Amu-Daria and the Syr-Daria, each having a length of more than 2,000 kilo-

meters (1.240 mi.), and flowing in a northwesterly direction, and having their sources in the high hills on the south frontiers of the Empire.

The rivers of Russia generally have their banks rising from 6 to 8 meters (20 to 26 ft.) above low-water level in the cases where these banks are of alluvial formation dependent upon the height of rise of the water in summer and at spring floods. In the cases where the rivers during their courses intersect elevations and mountain ranges, the channel of the river is narrowed and the banks become higher.

The high elevations of the sources of the rivers of Asiatic Russia appear to be the reason why, in general, the velocities of the flow of their currents are considerably greater than the velocities of flow of the currents of the rivers of European Russia, the average velocities being from 5 to 6 meters (16.4 to 19.7 ft.) per minute, and in other places the velocities attain 10 and 20 meters (32.8 to 65.7 ft.), and even up to 60 meters (197 ft.), as, for example, on the Great Rapids on the river Yenesei, where the river emerging from the mountains intersects the Sviasky Mountain Range.

The total length of all the navigable and raftable rivers of European Russia amounts to 180,000 kilometers (111,850 mi), therefore for each 30 square kilometers of the area of the Empire there is one kilometer of waterway (18.7 sq. mi. per mile).

In Asiatic Russia the navigable and raftable waterways are registered as 100.000 kilometers (62,100 mi.), that is, for each 170 square kilometers of area there is 1 kilometer of waterway (104 sq. mi. per mile). It may be that in the total reckoning up of these waterways of Asiatic Russia, all of the rivers may not have been included; but if this omission be rectified there will still prove to be for each kilometer of waterway of Asiatic Russia considerably more area of land than in European Russia, which is fully explained by the topographical difference of these portions of the Empire and their climatic conditions; namely, the flatter slopes of the rivers of European Russia more conveniently allow of taking advantage of the nature of the water escaping on the surface of the earth, and the total quantity of atmospheric deposits on the Asiatic continent is only half of that on the European.

The maximum quantity of water passes through the rivers of European Russia in the spring, after the thawing of the snow which has fallen on the surface of the earth during the many months of the winter and has been retained upon it in a solid state. At that time the rivers carry the largest quantity of water and are most convenient for navigation. This condition is taken advantage of for using the river, and large quantities of timber, as well as other goods, are conveyed down the river in the spring with the current. The rise of water in the spring in many instances amounts to 15 meters (49 ft.). The duration of the period of high water is for about a month and a half, but this depends upon the velocities of the currents and the extent of the basins—in the upper parts of the large rivers and in the small rivers, high water continues altogether sometimes for only two weeks; and in the very small rivers and near the sources of the large rivers, sometimes for only a few days.

The character of the Asiatic rivers with regard to the run-off is somewhat different. In the northern parts the water in the rivers rises very high during the period of the thawing of the snow, but in the southern parts the thawing of the snow does not give much water, in consequence of which one can see rivers—for example, the Syr-Daria and Amu-Daria—where the period of high water is during the months of June and July, when the maximum thaw of the snow on the mountain tops takes place. In the basins themselves of these rivers very little snow falls, and therefore its thawing does not cause a high rise of the water.

Besides the above-mentioned causes for the rise of the water in the rivers of Asiatic Russia, in their northern portions rains have a great influence. The level of the river Lena, for example, rises several times during the summer to a height of from 6 to 8 meters (20 to 26 ft.) above the low level. On the Syr-Daria and the Amu-Daria, which flow through the southern parts of Asiatic Russia, where, during the summer, rain never falls, such variations of water level never occur.

On the rivers of European Russia, the variations of water level caused by rains, although they occur, are not so considerable; nevertheless, there are rivers which are subject to such

floods, as for example, the Dniester and Oka flowing into the Volga, etc., where the variations in the water level of these rivers caused through rainfall amount sometimes to 4 meters (13 ft.).

The rivers of the Russian Empire are covered with ice for from five to six months in the year, the northern rivers for a longer duration of time than the southern rivers; besides, the duration of the period of being ice-covered varies on one and the same river for different years, depending upon the duration of the period of the low condition of the temperature. The ice on the Russian rivers attains extremely great thicknesses; at the beginning of the winter its thickness is only a few centimeters, but in January it is from 30 to 60 centimeters (12 to 24 in.), and even more.

At the time when the rivers are covered with ice all traffic on them ceases; by no means can the navigation be continued. Icebreakers of the ordinary type cannot be used on account of the depth of water on the shallow places, which will not permit of this, and icebreakers to conform to these special conditions have not yet been constructed; and besides this, a very large number of icebreakers would be required for breaking the ice on the long distances on the Russian rivers, so that the cost of construction and upkeep of such would counterbalance the advantages and profits that might be expected from them.

The nature of the Russian rivers to become covered with ice for prolonged periods considerably decreases the advantages that they could afford to the State as means of communication.

During the period of the formation of the ice covering, the ice moves along the river at first in small separate ice floes, and then the floes are gradually united together by the frost until such dimensions are attained that the ice is forced to stop on the rivers with swift currents; this movement sometimes stops only when the full section of the river in several places is packed with ice, and forms ice drifts or barriers.

It sometimes happens that the rivers pack with ice for a distance of 5 versts (3.3 mi.), and in this manner form ice barriers which are undestroyable until the spring, and the water flows round them along the shores, forming a new channel.

The autumn moving ice is not particularly dangerous for navigation, because the ice in the autumn is rather thin, and it is sufficient for the vessel to get under the protection of any bend to be out of danger; should the vessel be forced away by the ice, it cannot be carried very far from the place where it stood, because the stoppage of the ice will comparatively soon take place.

The spring passage of the ice on the Russian rivers takes place during high water, sometimes when it has risen from 8 to 10 meters (26 to 33 ft.) above the low-water level, i. e., when the height of the water is such that the ice can no longer hold on to the banks. If in spring the temperature of the air suddenly rises considerably, the snow thaws very quickly and running into the river raises the level of the water; the ice does not have time to move away, being yet comparatively solid. In this case the moving spring ice is very strong, and is very dangerous for vessels wintering in the river. Sometimes there is a gradual rise of temperature and the ice then has time to become porous and thin; the moving ice is then less dangerous for vessels. But, in any case, the wintering of vessels in the river must always be reckoned in the worst light, and it is therefore generally necessary to avoid leaving them for the winter in the river, it being better to shelter them in the old streams or in the mouths of the tributaries not falling at one and the same time into the main river, or in artificially constructed harbours.

The amount of trouble requisite for the purpose will not permit of a description in this article of each separate river, even though we should confine ourselves to very brief descriptions, and we will, therefore, only give such for the principal river basins which, at the present time, are of the most importance for the transportation of goods in the Volga basin.

The river Volga, which is the largest in Europe, has its source in the Tver Government on the Valdai heights, has a length of 3,750 kilometers (2,330 mi.), and receives numerous tributaries, the total length of which amounts to 45,400 kilometers (28,210 mi.). Of this number, on both sides, 15,685 kilometers (9,746 mi.) are navigable.

The basin of the Volga has a total area of 1,350,000 square

kilometers (521,200 sq. mi.), with a population of over 45,000,-000 people. Along the shores of the Volga there are situated 1,000 villages and 42 towns, of which 8 are district towns, namely, Tver, Yaroslav, Kostroma, Nijni-Novgorod, Simbirsk, Samara, Saratov, Astrachan.

The source of the Volga consists of a stream 1 meter (3.3 ft.) wide and 91 kilometers (56.5 mi.) long. Below the source a dam is constructed enclosing a water reservoir having an area of 170 square kilometers (65.6 sq. mi.) and containing up to 370 million cubic meters (13,066 million cu. ft.) of water, for the purpose of storing the spring water for feeding the upper Volga during the dry time of the summer. The width of the river below the water reservoir is from 40 to 65 meters (131 to 213 ft.); at 170 kilometers (105.6 mi.) lower down, at the town of Rjev, it widens to 100 meters (328 ft.); and afterwards it gradually increases in width until between Rybinsk and Nijni-Novgorod at some places it becomes 1 kilometer (0.62 mi.) in width, contracting in places to 270 meters (886 ft.). The valley of the river for the whole of its length to Nijni-Novgorod is for the most part narrow in the upper portions, in places being only up to 2 kilometers (1.24 mi.). Lower down, between the confluence of the chief tributaries of the Volga, the Oka and the Kama, the width of the river valley in places increases up to 13 kilometers (8.1 mi.), contracting in places to from 2 to 3 kilometers (1.2 to 1.9 mi.). The width of the low-water channel at this portion is from 300 to 1,600 meters (984 to 5,250 ft.). The greatest width of the valley of the Volga at the place where it divides into branches is 29½ kilometers (18.3 mi.), at the village of Oundor.

Between the towns of Stavropol and Syzran the Volga makes a sharp turn, forming a bend of 250 kilometers (155 mi.) in length. Beginning at Saratov, the Volga flows at a level lower than the Black Sea.

The depth of the Volga is extremely varied in the upper portions, the navigable depth, that is, the depth on the shallow parts, being about 0.6 meter (2.6 ft.); during the summer low-water period it is kept at this by releasing water from the upper Volga reservoir. Lower than Rybinsk, from the mouth of the tributary Scheksna, flowing into the sluice system of

communication between the Volga and Petrograd, the depth on the shallows sometimes amounts to 0.9 meter only (3.0 ft.), but ordinarily it is not less than 1.2 meters (4 ft.). Between the mouths of the Kama and Oka the depth is not less than from 1.6 to 1.8 meters (5.2 to 5.9 ft.), but at the same time, however, it must be remarked that the retention of this navigable depth requires the use of energetic dredging. In addition to this, improvement works have been carried out, and amongst such works, one of the shallowest reaches of the Teliatchie rapids was so improved. Lower than the confluence of the river Kama, the navigable depth of the Volga is 2.15 meters (7.0 ft.). Flowing into the Caspian Sea, the Volga forms a delta having an area of about 17,000 square kilometers (6,560 sq. mi.), with a width of up to 215 kilometers (134 mi.). The principal branch of the Volga intersecting the delta is the Bachtemir Channel, which has a depth of 2.75 meters (9.0 ft.), attained by dredging.

The minimum volume of flow of the Volga at Yaroslav, 85 kilometers (53 mi.) lower than Rybinsk, is 237.85 cubic meters (8,400 cu. ft.) per second; the maximum is 2,803 cubic meters (98,986 cu. ft.). At Tzaritzin the minimum is 3,228.38 (114,012 cu. ft.), and the maximum 26,613 cubic meters (939,439 cu. ft.) per second. The velocity of flow of current on the rapids is from 0.9 to 1.5 meters (3.0 to 4.9 ft.) per second; on the reaches it is from 0.3 to 0.9 meter (1.0 to 3.0 ft.). The average duration of the navigation is from 164 to 227 days.

The principal tributaries of the Volga are the Oka and the Kama. The former connects the Volga with the Moscow industrial district, and with the town of Moscow itself by means of the river Moskva, a tributary of the river Oka. The latter, the Kama, connects the Volga with the Siberian rivers. Besides these tributaries, there also flow into the Volga the rivers Schecksna, Mologa and Tvertza, connecting by artificial canals with the basin of the river Neva, the best arranged route running through the river Schecksna, namely, the Mariensky system. The other tributaries of the Volga, the Ounja, Vetlouga, Soura, have local importance.

The river Oka flows into the Volga from the right-hand side, and runs through several Governments. On it are situ-

ated 17 towns, the principal of which are: Orel, Kalouga, Riazan, and Nijni-Novgorod.

The total length of the Oka is 1,517 kilometers (943 mi.), on 1,230 kilometers (764 mi.) of which steamers run. The source of the Oka is situated at 196 meters (643 ft.) above the level of the Baltic Sea. The width of the Oka Valley varies from 4 to 10 kilometers (2.5 to 6.2 mi.); the banks rise from 6 to 8 meters (20 to 26 ft.) above the summer low-water level, and in some places to from 64 to 150 meters (210 to 492 ft.).

It is navigable from the town of Orel, where there is a dam impounding a reservoir capable of containing 20,000,000 cubic meters (706,300,000 cu. ft.) of water. The water being let out from this dam keeps the river at a navigable level below the town of Orel. The width of the low-water channel of the river at Orel is 65 meters (213 ft.), and in the Riazan Government about 210 meters (689 ft.). The maximum width is 530 meters (1,739 ft.), and near the mouth, 470 meters (1,542 ft.).

The navigable depth at the Riazan mouth part is 0.71 to 0.88 meter (2.33 to 2.89 ft.), with rare exceptions. Above Riazan to Kolomna, in former times the depth sometimes fell to 0.53 meter (1.74 ft.), but now, after the construction of two dams with sluices, the depth has been increased to 2 meters (6.6 ft.).

Between Kolomna and Kalouga the depth on the shallows is from 0.35 to 0.44 meter (1.15 to 1.44 ft.), and from Kalouga to Orel 0.1 to 0.26 meters (0.3 to 0.85 ft.).

The velocity of the current on the rapids is from 1 to 1.5 meters (3.3 to 4.9 ft.) per second, and in the reaches from 0.6 to 0.1 meter (2.0 to 0.3 ft.). The number of days for navigation on the Oka is from 204 to 215.

The river Moskva has a length of 455 kilometers (283 mi.), and a width near the town of Moscow of 85 meters (279 ft.), and at its confluence with the river Oka, 170 meters (558 ft.). Down to the capital, the river is shallow, but below the capital a depth of 1.1 meters (3.6 ft.) is maintained by means of 6 dams and sluices which have been constructed on it. The rivers Moskva and Oka, with their lower portions, form the Moscow-Nijni-Novgorod water communication, the length of which is 970 kilometers (603 mi.).

The river Kama commences in the marshes of the Viatka Government. Its total length is 1,882 kilometers (1,169 mi.). Ordinarily, one bank is high and the other low. The total fall is 244.36 meters (801.7 ft.). The Kama is navigable for a distance of 1,215 kilometers (755 mi.) of its lower portion, from the junction of the river Vischera. The width of the summer low-water channel in the upper part of the navigable portion is from 20 to 420 meters (66 to 1,378 ft.). Lower than the village of Dedouhin, which is situated 291 versts (193 mi.) lower down than the mouth of the Vischera, the width of the Kama becomes 850 meters (2,790 ft.), and more. The depth in the reaches is very considerable; on some of the rapids of the upper course the depth is 0.7 meter (2.3 ft.), and lower than the village of Dedouhin, with rare exceptions, the depth is not less than 1 meter (3.28 ft). The following portion of the river Kama, from the mouth of the Tschousova to the confluence of the river Belaya, a distance of 537 kilometers (334 mi.), has a channel of a width of from 370 to 1,000 meters (1,214 to 3,280 ft.), the depth on some of the rapids being 1.7 meters (5.6 ft.), and on most of the shallows not less than from 2 to 2.5 meters (6.6 to 8.2 ft.). Navigation is here freely carried on, with the exception of there being a few narrow parts of the channel, amounting to 50 meters (164 ft.) in width. Below the confluence of the Belaya there are only two rapids with depths of from 2.5 to 2.8 meters (8.2 to 9.2 ft.), the remaining portion of the Kama being extremely deep, having wide channels and there being no obstacles to navigation.

The river Tschousova, a tributary of the Kama, has its source in the Ural Mountains, near the river Izet of the river Obi basin, and is not of great depth. By means of these two rivers it is proposed to connect the river Obi with the Kama.

The river Schecksna, by means of which the Volga basin is connected with the Neva basin, has a length of 434 kilometers (270 mi.), and commences at Lake Belaya. The current of the Schecksna is meandering; on the upper portion its width is from 85 to 125 meters (279 to 410 ft.); on the lower portions, from 150 to 250 meters (492 to 820 ft.); the banks are steep and have a height of from 8 to 17 meters (26 to 56 ft.).

On the shallows of the Schecksna the depths are not less than 1 meter (3.3 ft.).

For maintaining the depths on the upper portion of the river, four dams of the "Poire" system with sluices are constructed. The upper lock has a length of 106 meters (347.8 ft.) with a breadth of 12 meters (39.4 ft.); the lower locks have the same breadth, but with a length of 339 meters (1,112.2 ft.), which allow of the simultaneous passage of several vessels through them.

The last dam is constructed at 312.5 kilometers (194.2 mi.) from Rybinsk. At the present time work is being carried out on this river for the construction of another five dams with sluices, with the object of increasing the navigable depth of the river to 2 meters (6.6 ft.).

The above-mentioned tributaries of the Volga, the Mologa and Tvertza, which are included in the group of the artificial waterways connecting the Volga basin with the Neva basin, have not very great natural depths.

The Volga fleet comprises 2,303 steamers. The total indicated horsepower of these steamers is 600,000. The total cargo capacity of all these steamers (not tug boats) is 3,000,000 tons, which gives 5 tons for each indicated horsepower. The total number of all the vessels, not steamers, of the Volga basin is 6,998, and the total cargo capacity of all the vessels 8,000,000 English tons, i. e., 2.5 times more than the cargo capacity of the Volga steam fleet. This relation corresponds with the conditions of the work of the fleet, and is explained by the fact, that for the loading and unloading of the non-steam vessels considerable time is required, during which the steam fleet is occupied with the conveyance of the remaining portion of the loaded vessels, as also, that the non-steam vessels are frequently used as stores for the goods. This frequently takes place especially with naphtha, as the passing steamers take their naphtha fuel direct from the naphtha barges.

The numerous tributaries of the Volga, as also the Volga itself, have extremely varied depths and widths of channels, and therefore the sizes of the vessels, steam as well an non-steam, are extremely varied, depending upon the local conditions under which they must work. For the more definite

determination of the sizes of these vessels, the following data are given: breadth less than 1.83 meters (6 ft.), without paddle boxes, there are 822 steamers; more than 11 meters (36 ft.), there are 26 steamers. The broadest steamer has a breadth of 15 meters (49.2 ft.), and with the paddle boxes 19.4 meters (63.6 ft.). Of a length of less than 18.3 meters (60 ft.), there are 637 steamers, and of a length of more than 73.2 meters (240 ft.) there are 22 steamers. The longest steamer has a length of 109.7 meters (360 ft.).

Of the total number of non-steam vessels, 1,269 vessels have a length of less than 18.3 meters (60 ft.), and 1,550 vessels have a length of more than 73.2 meters (240 ft.). The largest vessel has a length of 146.3 meters (480 ft.). Of a breadth of up to 3.66 meters (12 ft.) there are 422 non-steam vessels, and of a breadth of more than 11 meters (36 ft.) there are 2,392 vessels, of which the largest has a breadth of 22 meters (72 ft.).

The steamers running in the Volga basin are flat bottomed, of the ordinary river type, with iron hulls and wooden superstructures. The passenger steamers frequently have two decks —an upper and a lower. These steamers are principally driven by paddle wheels. In the Volga fleet, at the present time, there are vessels with "Diesel" engines; some of these vessels are fitted for passenger traffic, and some for towing.

The non-steam vessels, for the greater part, are made of wood, but there are also iron vessels. The principal type of non-steam vessels is the barge of rectangular shape with very slightly sharpened ends—the barges are covered above with a deck, and sometimes on the deck there are cabins. Their construction is very substantial. The other vessels have also the same shapes, with very slightly sharpened fore and aft ends, and differ very slightly from the barges in shape and dimensions. A few of the types of vessels have no decks.

The names of the types of the vessels are generally derived from the names of the places where they are built; to such vessels belong the Ounjatkie, which are built on the river Ounja, the Tihvinkie, which are built on the river Tihvin, and others. One of the most remarkable types of vessels is the Belyana, built of wood for the conveyance of timber materials. This vessel carries up to 16,000 tons of cargo, is built for one

voyage, and is broken up at its place of destination. The Belyana floats along, and for the better steering of it, stones on chains are lowered down from the vessel.

On all the waterways of European and Asiatic Russia 4,300 steam vessels are plying, having collectively 580,000 indicated horsepower. The total number of all the non-steam vessels of the Russian fleet is 24,151, their total cargo capacity being 13.5 millions of tons.

If these figures are compared with the corresponding figures of the Volga fleet, one can see that the number of vessels of the latter comprise almost half of the number of vessels running on all the rivers of the Empire, and their total tonnage is two thirds of the total tonnage of all the vessels of the Russian fleet.

In this way the navigation of the Volga basin is the most highly developed. This has been facilitated by the geographical position of the river, as well as by its navigability and the depth and width of its channel and the absence of natural obstacles to navigation, such as the rapids on the river Dnieper which divide it into two separate, independent portions which have nothing in common between them; and as also on the Yenesei, where one of the obstacles to the development of navigation is the velocity of the current. On the Volga the current is slow, which is very favourable for navigation.

With regard to its geographical situation, the location of this river in the eastern portion of European Russia, far removed from any seaports, gives it great importance for cheap conveyance by water to places in the proximity of the rivers of this district.

It is likewise necessary to remark that the Volga does not run into any open sea, as the Caspian Sea, into which it flows, does not possess any water connection with the neighbouring seas, and therefore its importance for foreign trade is not great —it serves only for trade with Persia, and for the home transport of goods.

At the lower portion of its course, near Tzaritzen, the Volga approaches the Don to within a distance of 85 kilometers (52.8 miles), and there is a railroad here which can transport the Volga goods to the Don, and consequently to foreign ports;

but this, of course, does not alter the fact of its not having an independent outlet to the open sea.

The Volga goods are also delivered to the railroads at other localities, and consequently are transported by these railroads to other parts. Large quantities of the Volga goods are sent north, and these are not only conveyed by the railroads, but are also conveyed by the waterway system which connects the Volga with the Neva basin.

The Volga, with its numerous tributaries serving an enormous district, permits of its being possible to make the goods up into large groups, which are presented for despatch by these various routes at many points on this river. The sizes of the groups in which the Volga goods are transported vary considerably, depending upon the nature of the goods: for instance, naphtha is transported in shipments averaging from 1,700 to 2,000 tons, grain and salt in parcels of more than 8,300 tons, and fish in parcels of about 2,700 tons. In consequence of this the freights on these goods vary, and when the average freight for the conveyance of 1 ton of naphtha for 1,000 kilometers (621 miles) amounts to 1.64 copecks (0.85 cents), the freight for the conveyance of coal amounts to 2.55 copecks (1.31 cents), and for salt to 5.34 copecks (2.75 cents) per ton.

On the other rivers the shipments are made in smaller parcels, depending upon the conditions of navigation on each individual river, as well as on other circumstances, the freights being considerably higher. Thus, for example, along the Dniester to Odessa, as well as along the Bug, grain is conveyed for 9 roubles ($4.635) per ton per 1,000 versts (663 mi.), along the Northern Dwina at 3 roubles and 60 copecks to 4 roubles and 20 copecks ($1.854 to $2.163), along the Lower Dnieper at 9 roubles ($4.635), along the Upper Dnieper at from 12 roubles to 14 roubles and 40 copecks ($6.18 to $7.416), and along the Don at from 11 to 12 roubles ($5.665 to $6.18). The freights on the Siberian rivers are still higher.

The difference between the freights on the Volga and the freights on all the other rivers is very great, on account of the conditions of navigation on them being much worse than on the Volga. On the Northern Dwina the freights are lower than on the other rivers, but this probably arises from the cheap-

ness of labour and living in the north. On the other rivers of European Russia the freights are more or less about the same, because the conditions for navigation on them are about the same. In comparison with the railroad tariffs, the amount of the freight charges is such as will permit of the competition of the railroads with the waterways; and, of course, without such improvements as would cheapen the carriage by water, the waterways can have little importance in the economic development of the country, because the goods which will bear a higher freight can always be conveyed by railway.

For Russia, as an Empire, in which distances are reckoned in thousands of versts, and in which the principal goods are of low values, a cheap means of conveyance for goods is necessary, and this is why at the present time the State is occupied with the improvement of the conditions for navigation of the rivers, to such an extent that the conditions for transport on them should be made similar to those on the Volga. For this purpose, at the present time, the construction of locks is now being carried out on the lower course of the river Don for a distance of 500 versts; on the lower course of the river Northern Don, which flows into the Don; two dams with locks are constructed on the river Oka; and the lower part of the river Schecksna is being provided with locks (the two latter have already been mentioned).

All these works represent only the commencement of the carrying out of gigantic schemes for the improvement of our waterways, with the preparation of which schemes a special commission has been for a long time occupied.

The next in rotation for the work of improvement on the Russian rivers is the improvement of the Dnieper rapids, which at the present time divide the Dnieper into two distinctly separate portions, neither having anything in common with the other. Legislation for the assignment of money for these works has been delayed in consequence of the war.

The radical improvement of the greater portion of the rivers of European Russia, for the purpose of making it possible to convey goods of low value along them, can be effected only by the construction of locks, as all these rivers are of very small depths.

The larger of these, the Don and the Dnieper, have depths of only from 0.7 to 0.9 meter (2.3 to 3.0 ft.), and are only maintained by constant dredging; whereas, for cheapening the cost of transport, a depth of 2 meters is necessary. Very few rivers are exceptions as regards depth, but amongst such exceptions may be included the Neva and the Svir, the sources for the waters of which are the Ladoga and Onega Lakes, which are not subject to great variations of water level, and which do not carry large quantities of deposits, and therefore the depth of these rivers is very great. The river Volga also has a comparatively great depth, but such a condition is only attained by energetic dredging, which costs 2,000,000 roubles ($1,030,000) per year. On the Volga there are also several regulating constructions, but such have been constructed only on individual small portions, and not in accordance with any general scheme, and therefore these constructions have had very little influence on the general depth of the channel.

The rivers of Asiatic Russia have very swift currents, and although their depths are comparatively not great, the foregoing condition greatly hinders navigation on them, as powerful steamers can tow only a very small quantity of goods; for example, on the Amu-Daria a steamer of 500 horsepower tows from one to two barges, each carrying 33 tons of cargo. The upper portions of the Asiatic rivers have likewise small depths, and some rivers are of small depth down to the very mouths; for example, the Syr-Daria and the Amu-Daria. To improve them and to adapt them for the traffic of barges having a draught of only up to 2 meters (6.6 ft.) is extremely difficult, as they have steep slopes, and to carry out the necessary work upon them would require the construction of a very large number of locks—to attain this depth by any other means would be impossible. Most of the rivers in their lower portions have sufficient depths of water and would not require improvement; it is only the swift velocities of their currents, as before stated, which present serious obstacles for navigation, and which unfortunately cannot be overcome.

The great velocity of current; the condition that the principal rivers of Asiatic Russia flow into the Arctic Ocean, the navigation of which is extremely difficult; that the rivers Amu-

Daria and Syr-Daria flow into the isolated Aral Lake; and that the river Amur has a bad exit into the Pacific Ocean, flowing into the Gulf of Tartary, are the reasons for the small significance of these rivers in the development of the industry of those parts, and its population.

The rivers of Asiatic Russia could become of greater importance if they were connected together into one general network, although through the drawbacks caused by their great velocities of currents, it would not be possible to decrease the cost of transport on them to the normal existing on the Volga.

The commission which drew up the scheme of work for the improvement of the waterways indicated such a waterway connecting all the above-mentioned rivers across Asiatic Russia, from the Volga to the Pacific Ocean. This route runs comparatively near to the southern frontier of the Empire, where the conditions for the transport of goods are more suitable than in the localities nearer the Arctic Ocean. On carrying out this work, the transport of goods will be facilitated and the rivers of Asiatic Russia will become of greater importance than they are at the present time, when they can only serve the isolated districts of their own basins. The conditions for increased population will also be better than at the present time, when the only continuous route across Asiatic Russia is the Siberian Railway, with its high tariffs. In the future the question has to be considered regarding the possibility of cheapening the cost of water transport on the swift currents which exist on the rivers of Asiatic Russia.

The total quantity of goods transported along the rivers of the Russian Empire in 1911 amounted to 50 millions of tons, and of this quantity only 2.5 millions of tons were transported along the rivers of Asiatic Russia, which amounts to only 5% of the total quantity of goods transported, and which figures confirm the very small degree of suitability of the Asiatic rivers for the development of the commercial exchange of goods.

If the operation of the railways of the Empire is compared with the working of the waterways, it appears that the latter transport only half of the goods that the railways transport by goods trains, the total quantity of which amounts to

100,000,000 tons, although the cost of railway transport is somewhat greater than the water transport. On this account, in European Russia the waterways do not fully afford the State those facilities and advantages which they could give, taking into consideration the cost of the outfit and the working of such water communications, which are considerably cheaper than with the railways.

Likewise, the advantage of the conveyance by water of cheap goods may at the present time be seen from statistical data; the distance of transport of goods by the waterways is twice the distance of transport of goods by goods trains, and this circumstance makes them especially valuable for districts with enormous distances dividing the various portions of the Empire. Apparently, in districts of great extent and possessing rivers for the conveyance of cheap goods, and where possible to do so, a mixed transport ought to be made by despatching the goods by railway from their place of origin to the large rivers, and along the latter to the ports at their mouths; and the goods from other parts being transported along the rivers to their upper parts, and from thence being forwarded for short distances by railway to their destinations. The direction of the railways must fulfill this requirement. This system of construction of ways and communications would be considerably cheaper than that which is now adopted in Russia, and which is confined to the endeavour to transport cheap water goods by railway.

Our waterways cannot serve for the transport of goods for the whole year, because for 5 or 6 months of the year they are covered with thick layers of ice, which make navigation impossible. The needs and requirements for the transport of goods become periodically greater and less; grain for example, is delivered for transport principally in the autumn and spring, and if only during the period of a portion of the year the valuable properties of the rivers were taken advantage of for the transport of cheap goods, agriculture would be benefited.

Because cheap goods are transported by the waterways, it must not be thought that the necessity for the construction of railroads for the conveyance of goods for long distances is removed. Such railroads remain a necessity and will convey

the more valuable goods requiring quick transport, and which will easily bear the higher expenses for more rapid movement. Cheap goods will be delivered to the railroads for forwarding in those cases where they will not have succeeded in being transported by the waterways. Such mutual cooperation makes it possible to quietly and with confidence contemplate the water transport, and to transport the goods cheaply and in a time which may be more or less correctly reckoned on before hand; this will cause a great activity in trade. Main lines of railways are therefore necessary; but on the transference of large quantities of goods to the water, the railways will be less overloaded if the transference of such goods is made systematically; and in this way, for some time to come, the increase of the goods traffic (which at the present time amounts to, on an average, 5½ percent yearly) can be arrested, will decrease the difficulty of the transport of goods by the railways caused through their congested condition, and will simultaneously increase the incomes of the railways. Upon the natural increase of the goods traffic, the transport of the cheap goods will be replaced by the transport of the dearer ones which are conveyed at higher rates of tariff.

The principal goods which are transported by water are timber and grain. About 28 million tons of timber are transported, principally in rafts. This timber is distributed throughout Russia for building and fuel purposes; some quantity of it goes abroad.

Grain is transported to meet the requirements of those districts of the Empire which do not grow it, and is likewise sent abroad. A total quantity of 360 millions of tons is transported along the waterways.

Likewise, for the Volga basin, naphtha and its products are transported to a total amount of 5.7 millions of tons. Naphtha is used for fuel on the Volga steamers, for factories, works, and railways, and a portion is sent abroad.

The fuel used by the steamers on the other rivers is coal, and even wood.

The coal is transported by the railways in very limited quantities, principally for fuel for the steamers. The larger quantity of coal, amounting to 22 million tons per annum, is

transported by the railways. This arises from the fact that approximately one third of the total amount of the coal produced is used as fuel by the railways, as also owing to the absence, in the vicinity of its production, of rivers suitable for transporting it. What has been stated with regard to mixed waterway-railroad transport specially relates to coal on account of the necessity for distributing this fuel through the whole of Russia cheaply, as otherwise the development of all kinds of manufacturing industries requiring fuel in large quantities will be retarded.

At present coal is principally produced in the Donetz basin, through which unnavigable rivers flow; the largest of them, the Northern Donetz, must be provided with locks, the project for which has already been drawn up. This river will then connect the Donetz basin with the waterway system, and coal will then require to be transported for short distances by railway, to the localities where required.

The principal means used for the improvement of the waterways of Russia, up to the present time, has been by dredging. On the Volga alone the yearly cost of this work amounts to 2,000,000 of roubles ($1,030,000), and altogether on this kind of work 3,000,000 of roubles ($1,545,000) is spent. Dredging gives very good results, and the general increase of the depth of channel on the Volga, for example, amounts to not less than 0.7 meter (2.3 ft.).

On the other rivers, dredging has not been so extensively carried out, and consequently the results attained are considerably less. Each verst of regulation work on the Russian rivers would cost considerably more than on the German rivers, on account of the very great variations of water to which the Russian rivers are subject.

These large outlays, as well as the heavy expenses for keeping the plants in order, would not correspond with the economic advantages derived from such improvements.

Besides the foregoing means of improvement, one can also point out the application on the Russian rivers of the use of water storage reservoirs. On the upper Volga, for example, a water storage reservoir is constructed capable of holding 40,000,000 cubic meters (1,412,000,000 cu. ft.) of spare water;

on letting out the water from this reservoir the low level of the water at Tver rises 8 centimeters, and in places near the storage reservoir 30 centimeters. The quantity of water stored is sufficient for 75 days.

On the smaller rivers, systems of locks are used. The largest of this kind consists of four dams, with locks, on the river Schecksna. Very small systems of dams and locks exist on the river Stschar, which flows into the Niemen, and on other small rivers.

At the present time, larger rivers are being provided with locks—for example, on the Oka, Don, and Northern Donetz—and the results attained are very good. In those places where the depths were very small, for example, ¾ meter (2.5 ft.), at the present time there are no depths of less than 2 meters. The results attained can be preliminarily fully determined, and probably in the near future this system of improvement will be extensively employed on the Russian rivers, with the exception of the Volga, Neva, Svir, and the principal rivers of Asiatic Russia, which, on account of their sizes and depths, do not require such a system of improvement.

Besides these important works on the Russian rivers, work is being carried out for the removal of snags and stones, and for the deepening of the rocky portions of the rivers by blasting operations, etc.

Lastly, great attention is being paid to the marking out of the river-passes (channels) with warning signs.

On the above-mentioned work, during latter years, except the year of the war, on an average, the following sums were expended:

On the construction of hydrotechnical plant, dams, locks, strengthening the banks, weirs, harbours, etc.	5,000,000	roubles.
For keeping in repair the waterways and the plant already constructed	5,500,000	"
For the construction of dredgers, steamers and other vessels and craft, etc., necessary for keeping the waterways in good condition	5,300,000	"
For the repairs and upkeep of these vessels	10,000,000	"
For the marking out of the channels and attending to the navigation	4,000,000	"
For the studying of the waterways, and for the drawing up of projects for their improvement	600,000	"

Paper No. 29

NATURAL WATERWAYS IN THE UNITED STATES.

Review of Recent Progress and Present Tendencies.

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PROBLEMS PRESENTED.

In all countries where interior waterways are used for navigation to any marked extent, there arise many complex problems of which the most important are: First, the physical, based on the characteristics of the river, such as its discharge, slope, the permanency of its bed and banks, and the feasibility of treatment so as to make it suitable for navigation; second, the economic, based on the character and expense of the work necessary for such a purpose, together with the return on the investment that can be obtained.

These two classes of problems appeal in a more or less forcible way to different interests; the first, more properly to the river engineer, and the second, to those responsible for supplying funds—in the case of government work, to Congress. Within comparatively recent years, the work of building channels has been more and more carefully studied, in order to combine the best practicable solutions of all these problems; so that now no plan for a proposed river work is complete until the subject has been practically exhausted, on both the physical and economic sides, by the engineers proposing the plan.

STAGES OF INLAND WATERWAY DEVELOPMENT.

Interior navigation, in all countries, has passed through several well-defined stages. The first stage antedates the use of steam as a propelling power, commencing with the time when the only means of transportation was by animals or animal-

drawn vehicles, either wagons and carriages, canal boats or pack animals. This limited source of power restricted transportation lines to highways and canals. It was not until the use of steam was successfully applied to the shallow-draft river steamboat that the development of interior river channels really began. This occurred early in the 19th century, and afforded an enormous stimulus to the construction of new and larger canals and the improvement of natural river channels.

The second period in the history of interior navigation began with the development of the steam railways, which expanded at a surprising rate immediately after they were found practicable, particularly in those parts of the United States where ordinary roads and other means of communication were still largely undeveloped and unreliable. These railways soon entered into a vigorous competition with the rivers, canals and highways, and before long took over a large part of their commerce.

The third period in the history of interior waterways began during the latter part of the 19th century, when the industrial development of the areas adjacent to streams and the increase in population had provided more than sufficient commerce for the existing railways, and had left a large volume of freight which could be more cheaply handled by water than by rail. In the United States, during the first period above mentioned, the well-known canals, such as the Erie, Morris, Chesapeake & Ohio, and Delaware Canals, were built; and with the advent of the steamboat, a feverish eagerness to develop the river channels was felt throughout the large part of the United States extending from the Atlantic Coast over the interior of the country as far west as the Mississippi River. In the succeeding years this movement increased until but few streams of any importance were without some improvement of their facilities. Notwithstanding the enormous increase in railway mileage of this country, this impulse in river development has also gone on increasing, but, in many cases, without much relation to the amount of commerce carried. It is only recently that this river work has begun to feel the checking effect of the railway competition, which has, little by little, taken from some of our streams the bulk of their commerce. Improvements in rail facilities and

reduction of cost of ton mileage have, of late, given the railroads an enormous advantage.

For this reason, the third stage, in this country, in which the river resumes its former value, can not be said to have begun except in certain localities where population is much congested, such as on tidal rivers like those in the vicinity of Philadelphia, Providence or New York City, and perhaps in a few other similar regions accessible from the ocean for comparatively deep-draft ships.

DISTRIBUTION OF WATERWAYS.

In describing the present status and recent tendencies in river engineering in this country, and in giving a general view of progress in this important branch of the nation's activities, only the more conspicuous instances can be referred to in a paper of this kind, and only a brief general analysis given.

The work of deepening and regulating river channels in the United States has been much more extensive than is generally supposed. The amount spent on rivers, up to 1913, exclusive of harbors and canals, has amounted to $402,792,000, and there is at present river work under construction amounting to $187,064,000. New work recommended by the engineers, but not yet adopted by Congress, amounts to $130,315,000.

The interior natural waterways of the United States may be divided into four general divisions, corresponding to the main geographical divisions of the country. Foremost of these is the lake system along our northern border. The other divisions are the portions separated by the two main mountain ranges—the Appalachians on the east and the Rocky Mountains on the west. These divide the United States into three main portions, the Atlantic Slope, the Pacific Slope, and the Great Mississippi River Basin.

With the exception of the Hudson and the Delaware, there are but few large rivers on the Atlantic Slope, and these are largely tidal. On the Pacific Slope, the Sacramento and the San Joaquin Rivers form a system of navigation reaching both north and south in the State of California; and the Columbia River, farther north, offers a transportation line into the wonderfully rich and fertile Northwest.

It is in the central portion of the country, however, that

the greatest opportunities for channel construction exist, for the great Mississippi Valley is traversed by one of the longest streams in the world, which, with its tributaries, offers many thousands of miles of navigable waterways.

The distribution of streams in this country and their total navigable lengths are shown in the following table:

Streams	No. of streams	Navigable length (miles)
Tributary to the Atlantic Ocean	148	5,365
Tributary to the Gulf of Mexico, exclusive of the Mississippi River and tributaries	53	5,212
Mississippi River and tributaries	54	13,912
Flowing into Canada	2	315
Tributary to the Pacific Ocean	38	1,606
Total	295	26,410

(P. 28, "Transportation by Water," Report of Com. of Corporations, 1909, Part I.)

These navigable lengths must be considered as approximate, as definite lengths of navigable streams are seldom exactly determinable. Nearly all these streams are of comparatively shallow depths, and are, in the main, available for light-draft boats only. "Forty streams have a total of about 2,600 miles of 10-foot navigation, and 70 streams give about 3,200 additional miles of navigation of from 6 to 10 feet during the greater part of the year, making a total of about 5,800 miles of 6-foot and over river navigation. The greater number of these streams flow into the Atlantic, but few of these have more than 100 miles of such navigation. The longest connected river system is the Mississippi and its principal tributaries, with about 2,500 miles of 6-foot navigation". (P. 29, "Transportation by Water", Report of Commission of Corporations, 1909, Part 1.)

METHODS USED.

With the exception of the protection of the ports on the great lakes and the deepening of their approaches and connecting links, the main work on these waterways has been in the nature of channel development in the interior streams. It should be borne in mind that in this work greater difficulties of an engineering nature have been encountered than is usual

in the streams of the older European countries, on account of the greater magnitude of the work here and the variety of the engineering problems presented, but it will be noticed that most of the successful works here have their prototypes in some of the continental rivers, where longer experience than is available here has eliminated many of the weaknesses, and enabled the later works to embrace the best of the old world practice. It has thus resulted that there is scarcely a river or harbor project anywhere in the world in successful operation, the methods of which have not been improved upon and used somewhere in this country. Within recent years many new and original methods have also been adopted. Foremost among these new means is the invention of the suction dredge, the grapple, drag and self-closing dredge-buckets, which have reduced so markedly the cost of channel excavation of recent years; the invention of new methods of shore protection for rivers with unstable banks; the extensive use of reinforced concrete in lock and dam construction; the adoption of movable dams, and the enormous improvements in unloading machinery at terminals for ore and bulky freight.

The facilities for navigation presented by the natural waterways of the United States place it in the first rank of the nations of the world in this respect, and within the last decade much new work has been done towards making these facilities more easily available for use.

LAKE SYSTEM OF INTERIOR WATERWAYS.

It is on our northern border, where the Chain of Great Lakes presents the most important system of interior natural waterways of this country, that the most conspicuous example of national benefit is to be found. These inland seas are of enormous commercial advantage, and nowhere in this country can we point to an instance where the water routes have increased in usefulness to a greater extent than here. The depth of these lakes, the extent, and strategic location with regard to a special class of traffic make them superior in point of tonnage to any other system of interior waterways anywhere. The iron ore deposits at the western end of Lake Superior are the most important in the world; and the coal deposits in western Penn-

sylvania are of a magnitude and quality that make them a worthy complement to the ore fields, and well able to make the United States what it has become in the last twenty years—one of the foremost producers of iron in the world. Over one half of the traffic of this lake system is iron ore shipped from about four ports on the western shore of Lake Superior to about a half dozen ports on the southern or southwestern shore of Lake Erie. The Lakes in themselves present excellent channels for navigation, but obstructions at the falls in St. Marys River, lying between Lake Superior and Lake Huron, were a complete bar to the navigation of these lakes, up to 1855. At this time the portage railroad previously built around St. Marys Falls, in order to make possible shipments of ore by water over the remainder of the distance was superseded by the first lock canal around St. Marys Rapids. This canal was of comparatively small dimensions, but demonstrated the possibility of this method of handling freight. It was built by the State of Michigan, and admitted vessels drawing up to 11.5 feet, and cost about $1,000,000. This money was raised by selling 750,000 acres of public land donated by the United States Government for this purpose. In 1870, the United States undertook to widen the canal and increase the capacity of the locks, the entire existing work having been turned over to the United States by the State of Michigan and freed from tolls some years before. This new lock, known as the Weitzel Lock, was opened to traffic in 1881, at a cost of about two and two-thirds millions of dollars. Commerce responded at once to these new facilities, and in 1886 a third lock was commenced. This was built on the site of one of the old State locks and was opened to navigation in 1896. It cost about four and three-quarter millions of dollars, and is known as the Poe Lock. It is 800 feet long by 100 feet wide, and admits vessels drawing up to 17.7 feet. This lock was soon inadequate, as the commerce developed more rapidly than the Government provided facilities, and in 1907 a project for an additional lock with its own separate canal was adopted at an estimated cost of $6,200,000. It will have a length of 1300 feet in the chamber, 80 feet width, and have a depth of 24.5 feet on the sills. (See Fig. 1.) This lock is now under construction, nearly all of lock masonry being now finished. In 1912, a proj-

ect for a fourth United States lock was adopted, to have the same dimensions as the third lock, and was estimated to cost \$3,275,000. It will connect with the canal of the third lock. Work on this fourth lock is also under way, the excavation for the lock pit being about a third done.

The increased depth provided at the St. Marys Canal by the new locks made it possible to use deeper-draft vessels. This continued until obstructions in the river channels in Lake Huron and Detroit Rivers began to be felt. In 1902, a project

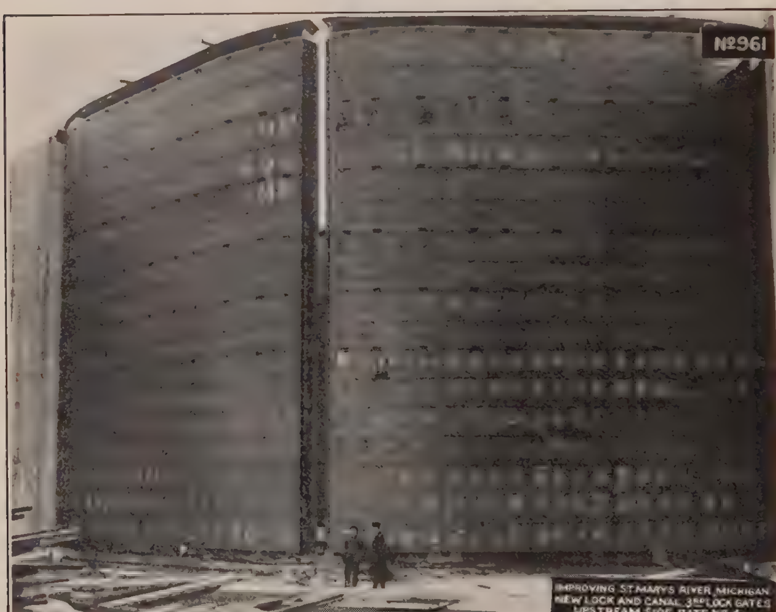

Fig. 1. The steel lock-gates for the new lock at the "Soo" Canal, Michigan.

was adopted to provide for removing shoals in the entrance to the Hay Lake channel, a part of Lake Huron, and for securing a new outlet channel from Hay Lake by way of the old line through the West Neebish channel. This project is now completed, affording a double channel from the Sault Locks to Lake Huron, having a clear depth of 21 feet. The expense of all this work has been \$8,400,000. It is worthy of note that the increase of depth and width in the old West Neebish channel was ob-

tained by diverting the water from this channel by coffer-dams, and then excavating the rock of the old river bed "in the dry." This was the more economical method (See Fig. 2). The work took about 5 years for completion, and involved the removal of 1,585,158 cubic yards of rock at a cost of $1.36 per cu. yd., and 5,461,120 cu. yds. of earth at a cost of $0.12¾ per cu. yd., and 3,324,275 cu. yds. of earth at $0.129 per cu. yd. These amounts are exclusive of "over depths", for which half these prices were paid.

Fig. 2. Rock excavation in the West Neebish Channel, Lake Huron. Work carried on within coffer-dams.

In the Detroit River, also, there were obstructions at Limekiln Crossing which originally limited the draft of vessels to about 12½ feet. As this river is on the route from the Lake Superior mines to the ore ports on Lake Erie, the deepening of this obstruction was needed as soon as the locks at St. Marys River admitted deeper-draft vessels than could pass these obstructions. In 1874, a project was adopted to provide for a channel from Detroit to Lake Erie having a width of 300 feet and a depth of 20 feet. This project was modified in 1888 to

provide for a width of 440 feet. In 1902, a greater depth was provided for, viz., 21 feet, and a greater width, 600 feet; and in 1910, a still greater depth of 22 feet was provided for. This channel, known as the Amherstburg Channel, is now complete, and cost $4,630,000. In 1907, a second channel was provided for, known as the Livingston Channel, and was opened to navigation in October 1912, at a total cost of $6,734,000. This provides a separate channel for up and down traffic in the Detroit River.

It will thus be seen that within a decade two new locks of great capacity are being added to the others already constructed, making four in all; and the channels at the upper and lower ends of Lake Huron have been deepened; and double lines for traffic provided, so that up traffic may use a different line from that going down.

These improvements have had a marked influence on freight and freight rates. In 1885, the tonnage through the St. Marys locks was 3,256,628 tons, valued at $53,413,472. In 1912, the traffic was 72,472,676 tons, valued at $791,357,837. The average of the five years, 1881-85, was 2,399,310 tons, and for the five years, 1908-12, was 57,519,763 tons, an increase of nearly 24-fold. The average distance that this commerce was carried was over 800 miles. The improvement in the channels since 1900 has enabled vessels to be increased in size from 8,000 tons to 13,000 tons, and the cost of transportation has been reduced from 1.18 mills per ton mile, in 1900, to 0.67 mills per ton mile, in 1912. It was estimated that the traffic passing the St. Marys River locks in 1912 amounted to upwards of sixty billions (60,000,000,000) of ton miles, and it was asserted that the saving in freight of 0.51 mills per ton mile was directly attributable to the channel improvements. It is worthy of note that the eastbound traffic greatly exceeds that bound westward, and that it is mainly bulk freight and mainly through traffic. Over one half of it is iron ore, and one fourth coal, the remainder being made up of flour, grain, lumber and miscellaneous freight.

MISSISSIPPI RIVER SYSTEM.

After the Great Lakes, the next most important system of interior natural waterways is the Mississippi River system.

This river, with its tributaries, affords a navigable mileage of 13,912 miles, and drains an area of about 1,300,000 square miles. In their original condition, the rivers of this system were streams of shallow depth, obstructed at intervals by shoals and snags, and at certain seasons have always been subject to floods of greater or less magnitude. As a means of communication, they were extensively used from the time that steam propulsion was first applied to the shallow-draft river steamboat. Before the construction of railways, they were the sole means of reaching many localities, but as rail construction increased their commerce has been largely taken over by the rail lines, in many cases. The most marked movement of the country's commerce is from the west to the east and reverse. North and south business is much less in volume. It thus happens that the Mississippi River and many of its tributaries do not lie along the direction of the greatest volume of traffic.

The early use of the streams depended on a successful application of steam power to a light-draft boat. The flat-bottomed shallow hull was thus a necessity. In order to get directive control in the swift currents, enormous rudders were necessary, and so the well-known gangs of three or four rudders set side by side were finally adopted, each very long, to act positively, and placed so that the preponderance of the length aft of the rudder post was slight, in order to reduce the power necessary to move them. The propelling power had to be applied in such a way as to give quick strong action in flood currents, and enable the rudders to act while backing. This required a powerful stern wheel. The type of boat evolved under these conditions has not changed much in recent years, and its efficiency has not been increased equally with rail power. The Government, however, has endeavored to examine into this question, and an appropriation of $500,000 was made in 1910 to make experiments with a view to reducing the expense of river towing on the Mississippi and its tributaries. Several experimental boats have been tried and are now being tested. Such favorable results have been met with in the twin screw "tunnel" type of steamboat that two are now being built for the lower Mississippi. Twin screws working in longitudinal tubes, or "tunnels", under and within the hull are the propelling power.

The Mississippi River is separated into three distinct parts; that above the mouth of the Ohio River, that between the Ohio and Missouri Rivers, and that below the mouth of the Missouri. In these parts, the differences in the character of the river and in the methods of channel construction are conspicuous. From St. Paul to the mouth of the Missouri River, 658 miles, the river was originally obstructed in many places by rock rapids and sand shoals. The first plan for its deepening was adopted in 1879, and provided for a channel depth of 4½ feet over the whole distance. This was to be obtained by open river regulation. Here is to be found the most perfect instance of this class of river work in this country, and is excelled in effectiveness nowhere. For upwards of 20 years the 4½-foot channel from St. Paul to the head of Lake Pepin, 54 miles, has maintained itself without cost; and below the Lake, although the improvements were not completed at the time of the adoption of the 6-foot project, more than 400 miles of the remaining 600 were permanently improved and the projected depth has been maintained at a nominal cost. The work has cost a little over $12,000,000. In 1907, it was proposed to increase the channel depth to 6 feet throughout the length of this part of the river, at an estimated cost of $20,000,000, with a view to its completion within 12 years. This project was adopted and work has been under way since then. The work is now about one third done.

The available water-power of the river at Des Moines Rapids attracted capital a few years ago, and the large market near at hand for electric power and the amount of water-power going to waste induced engineers to propose a commercial enterprise which would save this waste and assist, incidentally, in the navigation of the river. Accordingly, at Keokuk, Iowa, a power dam has recently been built by private funds, which raises the water surface 40 feet. This has covered the former Government canal around the Des Moines Rapids. It has backed the river up about 60 miles, affording 6-foot navigation for this distance. It is provided with locks for passing vessels. This work is a fine example of an industry that is increasing rapidly in importance in this country, and although primarily for producing electric power, it has, incidentally, helped the navigation of the river materially.

The commerce on this part of the Mississippi has not kept pace with the industrial development of the region through which it passes. The main reason for this is said to be that the commerce consisted principally of forest products, and as these diminish in supply there is nothing else that fully takes their place. The commerce of this part of the river in 1912 was as follows:

Designation	Tons	Ton-miles	Valuation
Logs	82,476	37,214,964	$403,216
Rafted lumber, shingles, etc.	10,918	3,718,643	155,452
Miscellaneous freight	1,265,589	13,469,619	25,693,493
United States material	471,311	3,506,680	425,490
Total	1,830,294	57,909,906	$26,677,651

(Page 2385, Report of Chief of Engineers, 1913.)

This tonnage is 12% less than that of the year before, and its value is 31% less. Although the freight rates by water are only about two thirds of those by rail, the disadvantages of inadequate terminals, the difficulty of transfer of freight, and risk are, together, apparently greater than the advantage of the lower rates afforded by the river. There has been a decrease in commerce on this portion of the river since about 1890, as is shown by the following table:

Commerce of the Upper Mississippi River (Annual Reports, C. of E.).

1890	4,200,000	tons (approximate)	Mainly logs and lumber
1895	2,975,000	"	
1900	2,900,000	" (approximate)	
1905	4,534,539	"	
1910	1,916,904	"	
1912	1,830,294	"	

A comparison of the shipments by rail and river at St. Louis has been made by St. Louis Merchant's Exchange, and by five-year periods is as follows: (P. 295, "Transportation by Water", Commission of Corporations, Part II.)

	By River	By Rail
1890	601,862 tons	5,270,850 tons
1895	303,355 "	5,349,327 "
1900	245,580 "	9,180,309 "
1905	80,575 "	15,225,973 "

From the foregoing, it will be seen at a glance that the river commerce at this point is not encouraging for the future

of river improvements. The signs all point to the fact that the facilities offered for traffic by the river channels are now far in advance of the use made of them.

In the section between the Missouri River and the Ohio, a length of 200 miles, the character of the river changes very noticeably, and we encounter a new class of problems presented by caving banks and shifting shoals (Fig. 3). These shoals are largely made of sand and gravel brought down by the Missouri in flood, and largely by the caving banks carried into the channel by scour. In this section the present project contemplates the maintenance of an 8-foot channel 200 feet wide throughout its entire length. This depth has been kept for many years, but only with constant work. In 1872, the first effort was made to deepen the shoals, which had then only 3½ to 4 feet of water on them, using solid dams and dikes of stone and brush to concentrate the low water flow into a single channel. These were only partially successful, and in 1881 the uniform depth of 8 feet was adopted for the entire section, and the use of permeable dikes and hurdles was actively begun. These were found successful in holding and consolidating the moving sediment of the river, and thus providing new banks where needed. In 1907, the project was radically changed as to methods, and since then dredging has been largely relied on for maintenance of the channel. Four hydraulic dredges of large capacity are now used in this work. Bank protection, permeable dikes, and hurdles are still extensively used, however, to produce permanent results. The last estimate of cost, made in 1903, was $21,000,000, in addition to the expenditures of about two and a half millions spent up to that time. In all, about fourteen and one-half million of dollars have now been spent, leaving over seventeen millions to complete the plan, which is now about one third done. The use of the river for commerce has fallen off to a fraction of its former figures, notwithstanding these large expenditures. This will be shown by the following table of traffic at five-year intervals:

Freight Traffic by Five-Year Intervals, 1890-1912 (Reports C. of E.).

1890	1,299,670 tons	1905	470,093 tons
1895	838,900 "	1910	191,915 "
1900	810,230 "	1912	205,720 "

Fig. 3. An example of a caving bank on the Mississippi River which it is necessary to control.

In the lower portion of the river, from the Ohio to New Orleans harbor near the head of the passes into the Gulf of Mexico, a length of nearly a thousand miles has been under the charge of the Mississippi River Commission since 1879. During all this time many experiments have been tried, and much has been learned with regard to this great river. Among the most noteworthy of these lessons is the importance of protecting the banks from caving and the greater reliance that can be placed on the operation of the hydraulic dredge. In this section, the project for a minimum channel depth of 9 feet with a 250-foot width has been maintained for many years with much success. The means employed have been the narrowing of the high-water width of levees and the maintenance of the width at and near low-water stages by bank protection, and by supplementing these methods by dredging on bars as they re-form. Much reliance was placed, a few years ago, on dredging as a sole means of improvement, and nine large-capacity suction dredges were built and are still being used; but the temporary nature of the work and the high cost of maintenance of channels by this method led to the more detailed study of bank protection. Between Cairo and New Orleans there are said to be over 750 miles of caving banks, corresponding fairly well to the length of one side of the river, and it is now believed that the greater part of the sediment of the new shoals is from this source. If the banks could be held from crumbling, the river would soon scour for itself a channel ample for navigation, and, furthermore, the protection from floods by levees would then be considerably simplified. A more serious effort is being made of late years to cut down this supply of sand by an annual extension of the bank protection (Fig. 4), and by 1912 a total of 68.71 miles had been completed. This work at Albermarle Bend alone is estimated to diminish the amount of material brought into the river annually by 11,000,000 cubic yards. The commerce on this river has dwindled to such a small part of its former volume that protection against floods is now the most serious problem of the engineers. Experience has shown that this is best accomplished by levees, and since 1890 about half of the appropriations for the lower Mississippi have been devoted to that purpose. A new grade for levee height has recently been adopted (1914) for all

United States work; but many levees have been built by state and local authorities, so but few are up to the Commission's level. When breaks occur it is almost invariably in one of these low levees, and is usually caused by overtopping.

The money appropriated for this section of the river since 1879, and expended under the Mississippi River Commission, amounts to over $77,000,000. Owing to the method of keeping statistics, it is difficult to determine the total commerce, as the river is divided into districts, in each of which the commerce is recorded separately. The sum of these would contain many

Fig. 4. Mat woven of poles and brush for bank protection on the Mississippi River. This mattress is continuous, and is built on the scow shown on the right.

duplications. Memphis to Vicksburg is a representative section, however, and would serve to show the tendency of commerce.

1902	1,856,339	tons	1908	1,661,406	tons
1903	1,940,026	"	1909	1,252,222	"
1904	2,018,222	"	1910	1,071,037	"
1905	2,040,598	"	1911	980,386	"
1906	1,855,830	"	1912	1,910,854	"
1907	2,355,901	"	1913	1,394,789	"

The insignificant use now being made of this magnificent stream, when compared with its capacity for transmission of freight, is thus apparent. On this river, soon after the Civil

War, there were to be found the most elaborate river steamboats ever seen in this country. Passengers, package freight, grain and cotton were hauled in great quantity, and with much profit. In the ensuing years railroads were completed along both banks of the river, practically the entire distance to the Gulf, and first passengers, then package freight, then cotton, and finally grain have almost disappeared from the river. Now the main items of commerce are logs, sand and coal. If this fine river could only have flowed from the neighborhood of Kansas City to some point on the Atlantic Coast, we might have a different condition to describe now, for the general direction of the greatest traffic movement is east and west.

At the mouth of the Mississippi there is a very excellent example of the successful deepening of river mouths in tideless seas. The necessity for this project was felt very early, and in

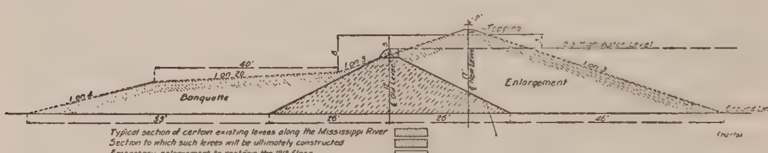

Fig. 5.

1854 a plan for an open river mouth was proposed by a board of three army engineers, of whom Generals Barnard and Beauregard were members. This plan contemplated using parallel jetties of rip-rap rock on mattress foundations, so spaced as to control and use for deepening the confined river currents. The mouth of the Rhone and its unfavorable experience with similar works were in part responsible for the delay in taking up this plan; but in 1875 Capt. J. B. Eads was given a contract to furnish a 26-foot channel with a 30-foot central depth through the South Pass, at a cost of $8,000,000. This sum was to cover maintenance for 20 years, or until 1901. It is now proposed to open a new channel through the Southwest Pass, 35 feet deep and 1000 feet wide, at an estimated cost of $6,000,000. This is the present project, adopted in 1902. Already, the jetties of this new project have been completed by contract, at a cost of $2,627,000, being begun in 1903 and completed in 1908. The work of dredging the channel has been

about four fifths completed. Of 18,000,000 cubic yards of dredged material which had to be removed in 1905, less than three and one-half million yards now remain. The original depth of 9 feet has now been increased to 31 feet.

THE OHIO RIVER SYSTEM.

The Ohio River is the most important tributary of the Mississippi, and indeed, it is the most important river of the country as a commerce carrier. In point of tonnage, Pittsburgh

Fig. 6. A fleet of coal barges passing Lock No. 2, Ohio River. The movable dam is up and is shown at the left.

has the largest commerce of any inland river port. This river, like all those of the Mississippi Basin, was originally shallow, crooked, obstructed by sand bars, and has always been subject to wide variation of discharge. Work was done on this stream, originally, as early as 1827. Snagging, rock removal and bar scraping were first tried, and later the channels were deepened, by placing wing dams at important places, to afford a 6-foot channel depth. Notwithstanding considerable success in this direction, this did not meet all the requirements of navigation

of late years, for new shoals would be formed in high water, and the uncertainties of open river regulation made the navigation precarious at low stages. But as work progressed, the river channels became more reliable and an enormous commerce, principally in coal and lumber products, grew up, owing to the favorable location of the stream, running as it did between the coal centers in Western Pennsylvania and the large cities along the Ohio and Mississippi Rivers. A terminal harbor

Fig. 7. A view from below of the single-leaf lock-gate of the Ohio River locks.

at Pittsburgh was soon needed. In order to more easily reach the important coal mines and to provide a quiet port in which loaded coal barges could be stored during low water in large numbers ready for flood stages on which they could move downstream, a dam in the upper part of the river was necessary. In 1877, one was built, and the success which this had led to the construction of several others lower down, in 1890, until, in 1910, a project was adopted for the canalization of the entire Ohio River, with locks and movable dams throughout its length

of about 1000 miles (Fig. 6). This project is to provide a depth of nine feet, and is now being constructed, 14 locks and dams having been completed, four will be finished during 1915, and 13 are now under construction. The estimated cost of the new project is over $64,000,000, and is one of the most comprehensive plans of river improvement ever undertaken in this country. The plan provides for 54 locks, with single-leaf sliding gates instead of swinging gates (Fig. 7), and includes dams

Fig. 8. The gate of a bear-trap dam under construction.

having bear trap sections (Fig. 8) and movable wicket sections (Fig. 9) so arranged as to furnish pools having 9-foot channels, at low stages, with all dams up. As the water stages rise, sections of the dam are dropped, until at high water no special obstruction to the flow of the river is offered and navigation can proceed over the dam without difficulty. This project was planned to be finished in 12 years. No records of the total commerce of this stream have been compiled during recent

years, but at the various locks statistics of traffic are kept. The records at the Louisville lock of the commerce passing this point have been maintained for many years. It is shown in the following table for five-year intervals, to indicate present tendencies:

1895	1,129,644 tons
1900	1,574,194 "
1905	1,242,250 "
1910	1,041,323 tons
1913	1,446,787 "

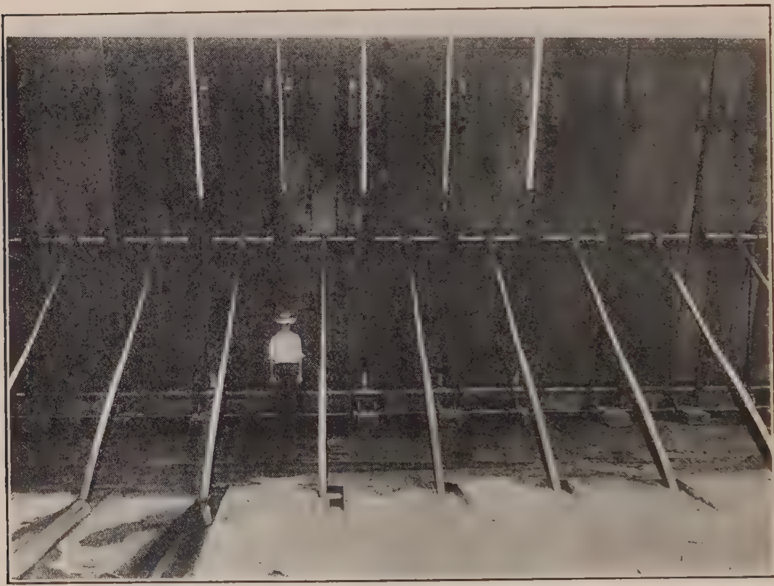

Fig. 9. The wickets of a movable dam on the Ohio River showing size and method of tripping.

The tributaries of the Ohio comprise an extended system of navigation which reaches a large part of the Mississippi River basin. Along these tributaries, most of which enter the Ohio from the south, are over 4,000 miles of navigable channels. Many of these tributary rivers are under improvement of a most modern and efficient type, and new projects of great interest have been begun on several within the last decade. The Kanawha River was the first to be equipped with movable dams. The project for this work was adopted in 1875, but it was not until 1897 that the work was completed. The total cost

was $4,158,000. This covered the construction of eight movable dams and two fixed dams, a system which has given a 6-foot depth throughout the length of the canalized portion of the river, of about 90 miles. Until the completion of railroads along the banks of this stream, the commerce, consisting principally of coal, was of considerable size, with every indication of a marked increase in the future. This stream, like so many others in the Mississippi basin, is not maintaining its importance as a freight carrier since the completion of the principal railroads, as will be shown by the following table. Notwithstanding a great increase in the production of coal in the region of this river, the commerce of this stream has not expanded:

1885	1,231,382 tons	1905	1,613,889 tons
1890	1,127,232 "	1910	1,122,102 "
1895	1,082,342 "	1912	1,276,540 "
1900	1,475,930 "		

The cost of maintenance during 1912 was $97,002.78. The movable dams on this river are of the Chanoine wicket type and have proven eminently successful in providing pools for 6-foot navigation. As an engineering problem alone, the solution has been very satisfactory.

The most important tributary of the Ohio, in point of traffic, is the Monongahela. On this stream are located many coal mines, particularly in the lowest six pools; and many of the steel mills of the Pittsburgh district are also on its banks in the lower part. Most of the traffic of this river is coal carried to the mills of Pittsburgh, or carried to the harbor of Pittsburgh in small tows of three or four barges, there to be made up into larger tows for shipment, at high-water stages, down the Ohio to other river points below. This river is canalized, by fixed dams, throughout its entire length of 131 miles. Traffic on this stream has increased enormously in recent years. The commerce in

1890 was	4,652,104 tons	1905 was	9,211,752 tons
1895 "	4,183,596 "	1910 "	11,486,278 "
1900 "	5,233,110 "	1912 "	11,575,239 "

This system of locks and dams on the Monongahela was acquired by purchase by the United States in 1897, at a cost of

$3,761,651.46, and since that time three locks have been rebuilt and their dams equipped with movable tops, at a cost of about two and a quarter million dollars. In 1913, Congress ordered the rebuilding of Lock No. 6, at an estimated cost of $356.200. This river has had a very marked effect on the enormous steel industry of its region, by reducing the cost of coal. Its location is very favorable, and it has had a very important share in the development of the great steel mills of the Pittsburgh district.

It should be mentioned, however, that the statistics of 1914 show that the commerce on the 55 miles of river above Lock No. 6 is insignificant as compared with the rest of the river. Although coal is mined along this part of the stream, comparatively little is shipped by water. The economic value of Locks 7 to 15 inclusive is thus seen to be slight. The reason for this is not apparent.

The Allegheny River, which joins with the Monongahela to form the Ohio, is mostly used in the lower 25 miles, where up-stream navigation is the main movement of traffic consisting mostly of Monongahela River coal for the steel mills along the lower six miles of the stream. Practically no coal comes down the Allegheny, for the reason that the coal fields, which are said to be as extensive as in the Monongahela Valley, are of thin veins and so cannot yet compete with the Monongahela mines. In this lower 25 miles the locks and dams were completed, No. 1 in 1903, No. 2 in 1906, and No. 3 in 1904, all at a cost of $1,690,000. In 1912, a new project was adopted by Congress providing for extending slack-water navigation about 36 miles further up-stream by constructing five new locks and dams, at an estimated cost of $2,788,000. No work has been done on this new project because of a provision of law which requires that before work can be begun, satisfactory assurance must be given that the channel spans of bridges which obstruct the river at Pittsburgh will be modified so as not to be in the way of vessels navigating the river. The commerce of this river for five-year periods is shown as follows:

1900	2,570,900 tons	1910	1,181,963 tons
1905	1,230,352 "	1912	1,667,126 "

Nearly all of the tributaries of the Ohio of any considerable size have been canalized, many within the last two decades. The

Muskingum River had been provided with locks and dams for 6-foot navigation by the State of Ohio and a private corporation between 1837 and 1841. This system was in a dilapidated state when taken over by the United States, in 1888, for rehabilitation, and at that time ten new locks were authorized, in addition to the repairs, and, later, another lock, known as No. 11, was provided for. This project has been completed for several years. The total cost for repairs and maintenance since 1888 has been $2,050,000. The commerce has been slight, as is shown below:

1910	58,956 tons
1912	64,214 "

The Little Kanawha, too, was equipped with locks and dams at an early date by a private corporation. It was not until 1905 that the United States purchased the four locks in the lower river, at a cost of $163,000. Before this, a fifth lock had been built by the Government, in 1891, above the lower locks. The total money expended on this river was $281,000, by which the 4-foot navigation of the river has been restored and extended up-stream for 48 miles. Commerce has not been important, and consists principally of logs and railroad ties, materials best transported in rafts at high stages without the aid of locks and dams. During the last 24 years, the commerce has been as shown below, during five-year intervals:

1890	140,115 tons	1905	106,510 tons
1895	179,240 "	1910	84,475 "
1900	119,439 "	1912	89,202 "

During the year 1912, $14,500 was expended in maintenance alone.

The Big Sandy River is another tributary where locks and dams have been built within comparatively recent years, but where the commerce has always been unimportant. Three locks and dams of the movable needle type have already been built in the main river, 27 miles long, and the present project provides for the continuance of the work up-stream by building 8 locks and dams on the Tug Fork and on the Levisa Fork, the two branches forming the river. These forks are also to be

provided with 6-foot depths of channel, under the project. One lock and dam has been built on each fork, but it is now very unlikely that the others will ever be built—certainly not for many years—as a re-examination into the worthiness of these streams for further expenditures has been recently reported upon adversely. The cost of the five completed locks and dams has been $1,558,000. The commerce consists principally of logs and railroad ties. It was originally hoped to reach the undeveloped coal fields at the headwaters of the forks by the river navigation, but the construction of railroads has made the extension of the slack water unnecessary and unprofitable. Commerce in recent years has been as follows:

1890	268,582 tons	1905	152,077 tons
1895	545,910 "	1910	147,725 "
1900	300,000 "	1912	188,743 "

A conspicuous instance of the extension up-stream of the slack-water system of one of these streams, long after the commerce has declined to an unimportant figure, is the Kentucky River. The lower five locks of this system were constructed by the State of Kentucky in the years immediately following 1835, but they had grown useless and dilapidated, due to neglect, long before the year 1879, when they were turned over to the United States for restoration. These locks were restored at considerable expense, and a new project adopted soon after, involving the construction of 14 new locks and dams, to extend the six-foot navigation up to Beattyville, at the headwaters, where it was hoped the coal veins would supply a volume of traffic that would justify the high cost of the work. If any hope of such a traffic was ever warranted, the railroads have since made it improbable of fulfillment. The estimated cost of the proposed work was $4,865,550. Of this amount, $3,870,000 has now been spent, and all the system completed except the two uppermost locks and dams. The principal present commerce of the river is logs and railroad ties, which are best floated down-stream, at high water, in rafts. In 1912, the commerce amounted to 186,300 tons. Previous years show a falling off of business, in spite of the greatly increased length of channel available. The commerce was as follows:

1890	310,354 tons	1905	124,871 tons
1895	296,318 "	1910	263,785 "
1900	162,891 "	1912	186,300 "

We see here an expensive system, costly to build and costly to maintain, without enough commerce to warrant the outlay. This result was predicted twenty years ago by the local engineers, but without effect. The Beattyville coal can never compete with Pittsburgh coal, even along the lower Kentucky River.

Several other small streams which empty into the Ohio have canalized sections. The Wabash River, flowing south from Indiana, has one lock and dam, having a five-foot depth over the sills and about a five-foot lift. It furnishes a pool about 12 miles long, but at low water vessels have difficulty in reaching the pool from the Ohio as, in fact, is true of many of the tributary streams. This lock was built in 1895 and cost over $260,000. The maintenance charges during 1912 were $7,651, and tonnage handled that year was 1187 tons. Since 1897, the maintenance has cost $86,398.97. The Green and Barren Rivers likewise have canalized portions, providing 5-foot navigation from the mouth in the Ohio to Bowling Green, Kentucky, and Mammoth Cave, a total distance of about 219 miles. The four old State locks in Green River and the one in Barren River were purchased by the United States in 1889 and restored to a condition for use, and two new locks were built in Green River a few years later. No. 6, the last of the series, was opened in 1906. The total cost has been about $2,086,000, exclusive of the cost of the 2 new locks, and the cost of maintenance, in 1913, has been about $89,000. The freight has been largely exchanged with Evansville, Ind., which is a market for the logs and ties which form the bulk of the traffic. Coal, on Green River, forms the third important item of commerce. The commerce at the lowest lock of this stream will not include some local business which is carried on in the river above, but will include through freight and will serve to indicate the change in commerce in this stream from year to year.

Commerce, Lock No. 1.

1890	907,146 tons	1905	466,015 tons
1895	344,833 "	1910	258,199 "
1900	378,684 "	1913	302,610 "

Farther west, the Cumberland and Tennessee Rivers empty into the Ohio. The Tennessee is over 650 miles long and the Cumberland 518 miles. On both of these streams, considerable new work has been commenced within the last few years. The Cumberland has a series of seven locks, extending from Lock A, 41 miles below Nashville, up-stream 166 miles, the last of which was finished in 1912, at a total cost of $2,418,952 for all seven. Lock A, below Nashville, cost $390,600, and Lock 21, near Burn-

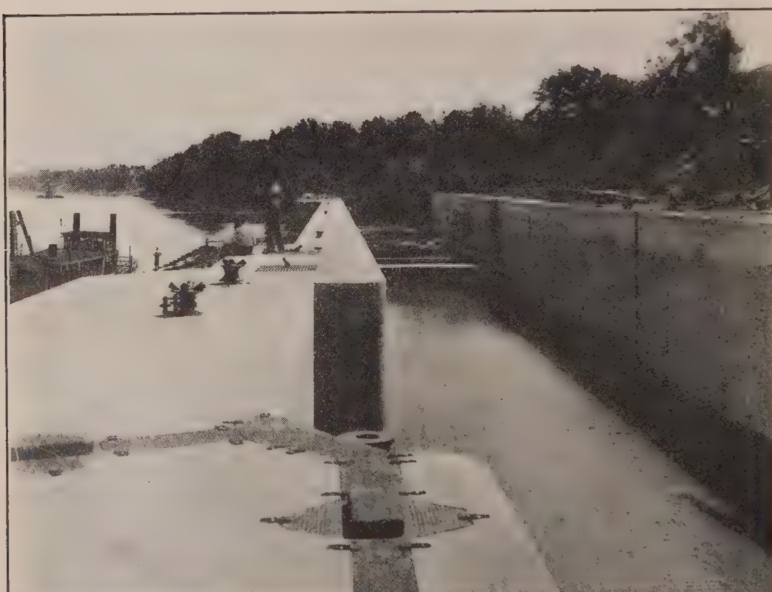

Fig. 10. A new concrete lock on the lower Cumberland River. The gates are not yet in place.

side, Ky., which was built to provide a harbor at the headwaters of the river, cost $374,076. From Nashville to the mouth of the river, 193 miles, no locks were built, and the stream was in a very unsatisfactory state on account of shoals during low-water season. It was not until 1910 that the lower section, connecting with the slack-water part already finished, was provided for, at a cost of $3,165,000. This covered the cost of five new concrete locks and dams. One lock just below Nashville, known as Lock A, had been finished in 1904 at a cost of $305,000. The work on the five new locks is now under construction (Fig. 10).

The locks are to be of concrete, with steel gates and fixed concrete dams, and will provide for 6-foot navigation from the Ohio to Nashville, and there connect with the upper river to a point above Carthage about 160 miles further. The nine locks now in operation cost $129,562 for maintenance in 1913. Commerce on the Cumberland has been as follows, consisting largely of logs and lumber:

1890	971,563 tons	1905	636,237 tons
1895	321,137 "	1909	418,192 "
1900	558,371 "	1912	484,744 "

Fig. 11. Rock excavation on the Tennessee River. Specially designed drill-raft boring preparatory to blasting.

Of all the tributaries of the Ohio, the Tennessee affords the greatest variety of regimen. The lower section, of about 236 miles, is somewhat like the Mississippi—a slowly flowing, crooked stream of small slope and comparatively large discharge, with low banks and soft, easily-eroded bed. Dredging is the form of improvement mainly relied on for channel deepening. The next 238 miles is what is known as the "mountain section", where swift currents, rocky beds, high and rocky banks, rapids and whirlpools are met with, requiring rock removal, canalization and lateral canals for their treatment. In the upper section, of about 188 miles above Chattanooga, the

bed and banks are fairly permanent, but the shoals and rapids make navigation difficult at low water. Here regulation by dikes and excavation tunnels is used. The river is 652 miles long and has tributaries which increase its channel length to 1300 miles, all of which can be used by steamboats, and 1000 miles more can be used by rafts and flatboats. Its drainage area is 44,000 square miles. The work on this stream, which began as early as 1835, was done in a rather disconnected way until 1909, when a single project for the entire stream was proposed, providing for 6-foot navigation from the mouth up to Chattanooga and 3-foot from Chattanooga to Knoxville and the

Fig. 12. Crane boat on Big Bend Shoal, Tennessee River. The grapple bucket handles the loosened rock, previously blasted, in one movement from channel to training wall.

up-stream end. The total estimated cost was $13,000,000, and twelve years the estimate of time in which the work should be completed for most economical results. Work is now under way on this project. In the lowest section the most formidable obstruction is a rock shoal known as Big Bend. This work is noteworthy, as specially-designed drill rafts are used for drilling and breaking up the bottom (Fig. 11), and a crane boat with a 90-foot boom and a grapple bucket are used to remove the blasted material (Fig. 12), the purpose being to place it in training walls on each side of the cut to act as guides for low water navigation, and thus avoid handling a large part of the

material by barge (Fig. 13). This work is now under way. The dredging and rock removal under the new project were estimated to cost $600,000 in addition to previous work. Already $534,000 has been expended on this section to secure a 5-foot depth of channel, and the additional amount is required to get the 6-foot depth necessary and complete the deepening of the remaining shoals. In the middle section are to be found the well-known Muscle Shoals, around which two canals aggregating about 15 miles length, with 11 locks, were opened to navigation in 1890, at a cost of $3,191,726. The maintenance of this canal has cost over a million dollars since then. The use

Fig. 13. A rock cut on the Tennessee River showing training walls along the sides, and a contracting spur on the left.

made of the canal has never reached its full capacity, but its value has been considerable to Chattanooga and Bridgeport. The completion in 1911, of the 8-mile lateral canal around Colbert Shoals with its 26-foot lift lock, and the construction of the dam at Hales Bar for power purposes are the most noteworthy new features of this section. The Colbert Shoals Canal was commenced in 1890 and has just recently been completed, at a total cost of $2,320,000. It is eight miles long, and provides for a draft of 7 feet. The huge dam at Hales Bar was built by private persons for power purposes, and has a lift of over 41 feet. The problem of foundations presented many difficulties, but the work is now practically complete. The foundations are

novel in river work in this country, and were made of concrete caissons sunk side by side in the river bed. From these the soft and imperfect rock of the river bottom was removed under air pressure and the caisson then "absorbed" in the foundation by filling with concrete. This dam and its appurtenances are said to have cost over $5,000,000, and are planned to provide 55,000 hp. when fully developed (Fig. 14). It is a notable example of the cooperation of private and governmental

Fig. 14. Hale's Bar Dam, Tennessee River, under construction. This dam has a 41-foot lift, and is being built with private funds under Government supervision for the creation of electric power.

agencies to secure the fullest development of the river's resources, both in the creation of electric power and the deepening of the river for navigation. Other interesting instances of recent construction are in the Mississippi at Keokuk, Ia., already referred to, and in the Coosa and Black Warrior Rivers in northern Alabama. In all, there has been spent on the Tennessee River a total of $7,393,496, made up as follows: $328,255 in the upper section, above Chattanooga; $6,531,210 in the

middle section, where the most obstructions exist; and in the lowest section, $534,051. The commerce in five-year periods is as follows:

Section of river	1890	1895	1900	1905	1910	1913
Above Chattanooga....	77,850	265,256	380,607	480,406	370,430	474,953
Between Chattanooga and Riverton............	6,474	117,357	229,160	175,800	288,750	315,218
Below Riverton...........	128,470	848,263	737,009	663,606	375,570	272,625

The Missouri River is the longest tributary of the Mississippi, being 2551 miles long. Its width is from 300 feet to one mile, and its depth over shoals is only about three feet. Its banks and bed are easily eroded, and the channels frequently shift in position. At various times between 1838 and the present, shoals have been deepened and snags have been removed from the channel at the worst places, but no systematic improvement was ever adopted until the project of 1884 was commenced, providing for revetting the banks, regulating the widths to fix the channels in location, and removing snags. In all, $14,175,378 has been expended on this river up to 1913. The work has not served to stimulate commerce, as was hoped, for the tonnage of the river remains noticeably disproportionate to the length and size of the stream. It has merely shown that a navigable channel can be obtained, although at a very great cost. The main efforts of the engineers have been directed toward the contraction of the river where necessary, rectification in other places, and securely holding the channel in place by using revetment on the banks and permeable dikes in the stream to collect and impound sediment at previously selected places. This disproportion between the high cost of an adequate channel and the small use being made of it during late years has reduced the interest in this river, and until recently the work has consisted principally in maintenance of existing conditions by protecting caving banks and removing snags. For eight years, 1884 to 1892, the river was under the direction of a commission similar to the Mississippi River Commission, but this method of administration has not been altogether successful, and it was abandoned on the Missouri in 1892. Notwithstanding these discouraging tendencies, in 1912 a project was adopted to provide a 6-foot channel, within 10 years' time, from the mouth in the

Mississippi up to Kansas City, nearly 400 miles, at a cost of $20,000,000. This work is now under way, the principal reliance being put on dikes and bank revetment assisted by dredging.

The commerce of this river below Sioux City, Iowa, has been as follows:

1895	154,334 tons	1910	876,130 tons
1900	263,114 "	1912	249,599 "
1905	343,345 "		

The foregoing analysis of the largest and most important rivers in the Mississippi River system will illustrate the tendency, so much more noticeable of late years than a decade or two ago, of the diminishing part the rivers in this great basin are playing in the up-building of this important region. Many other smaller rivers would accentuate this important fact still more strongly. Nowhere in this country are the products of the farms more abundant; nowhere are the mines more productive; nowhere is the industry of the population accomplishing more than in this vast area. Commerce is increasing by enormous strides, and rail lines have multiplied their branches. The total commerce at St. Louis, receipts and shipments combined, was 1,265,592 tons by river, in 1890, and 15,240,141 by rail. In 1906, it was 416,855 by river and 44,964,623 by rail. During these 16 years, rail business nearly trebled in volume and river commerce fell to one third of its 1890 figures (St. Louis Merchants' Exchange Report). Grain has almost disappeared from the rivers. Cotton is no longer carried in quantity. The main items of river commerce are coal, sand and forest products. Notwithstanding large sums for new improvements, nothing seems to have checked this decline in river commerce, wherever it has shown a positive tendency. With the exception of the Monongahela, and perhaps one or two other streams, the best that can be said for the busiest streams in this entire valley is that they are holding their own in tonnage from year to year, an admission in itself that the rivers are not sharing in the development of the region through which they pass.

The rivers entering the Gulf are, in general, comparatively unimportant as commerce carriers, with the exception of the

Mississippi, which as a Gulf port has a river commerce which amounted to 4,273,947 tons in 1912 at New Orleans, and for the ten years preceding it showed a substantial increase. The main Gulf rivers are those of Alabama and those of Texas. Of the former, the Alabama River with its tributaries is the most important, owing to its length of 825 miles of continuous waterway. This importance also arises from the location and direction as it proceeds from the interior of the State and flows to Mobile and the Gulf. The most recent project, that of 1910, provides for a channel 4 feet deep, at low water, and 200 feet wide, from the Mobile River, where depths are sufficient for river boats, up to Wetumpka, just above Montgomery on the Coosa River. The channels of the Coosa are partly through regulated and partly through canalized portions. Work on the Alabama River has already cost about $852,000, and on the Coosa, $2,045,000. The project for the Coosa provides for 23 locks and dams. The commerce of the Alabama in 1912 was 139,846 tons, valued at about $7,000,000; and on the Coosa, 52,342 tons, valued at a little over a million dollars. On the Coosa there is a notable example of a dam which is being built for power purposes under government permission. It has a lift of over 63 feet and is to be provided, later, with locks for passing vessels. It is now completed and in operation. It will pond the water back for over 15 miles and will furnish a navigable channel four feet deep, or more, for that distance.

The Warrior and Tombigbee Rivers form a continuous line of water communication from the mouth in Mobile Bay up to the forks of the Warrior River and to the Warrior coal fields, about 407 miles. The Tombigbee portion, 185 miles from the Gulf up to the Warrior River, has been made navigable for 6-foot navigation by the construction of three locks and dams and by regulating work, at a cost of $1,348,000. This work is now completed. The Warrior River is to have 15 locks and dams, of which twelve have been completed and two provided for by recent appropriation and one still to be built. The total estimated cost is $9,247,000, of which $8,743,000 has already been made available by Congress. At Lock 17, a dam 63 feet high is being built by private funds for power purposes. It will be equipped with two locks in flight to pass vessels. This

dam is now under construction and is practically finished. (Fig. 15.) The combined commerce of these rivers is comparatively small, amounting to 464,754 tons in 1913. The cost of maintenance of 13 locks in operation in 1913 was $122,000. The high first cost and large amount needed for maintenance will require

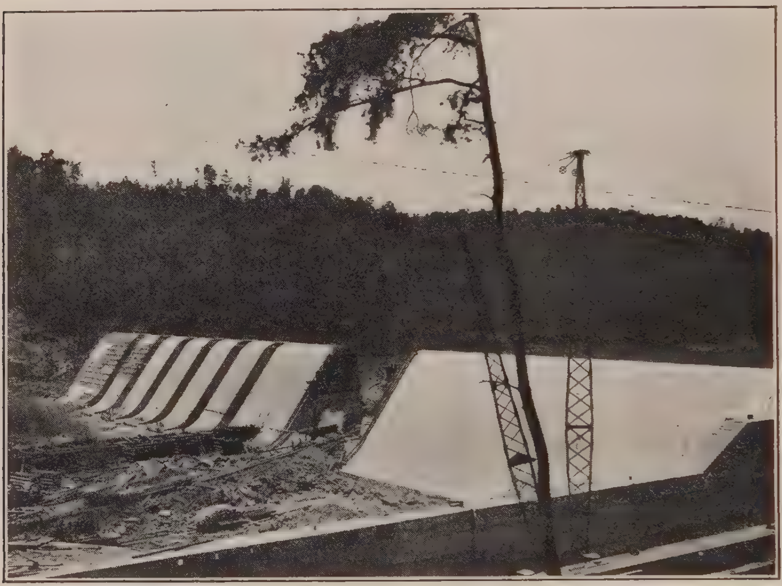

Fig. 15. Dam No. 17, Black Warrior River, Alabama, under construction. This dam has a 63-foot lift, and is being built by private enterprise for the creation of electric power. Looking toward the abutment end from the lock side.

a large increase in commerce if the work is to justify the judgment of those responsible for the undertaking. Commerce in

1890 was	57,868 tons	1905 was	250,000 tons
1895 "	37,291 "	1910 "	337,194 "
1900 "	360,950 "	1913 "	464,754 "

Of the Texas Rivers, the Trinity River is one of the longest in the State and has been navigated at favorable seasons for a distance of 120 miles up-stream from its mouth in Galveston Bay. It is a narrow, shallow, winding river with low banks. It was proposed in 1902 to provide a channel, by open river work and locks and dams, to give a 6-foot depth up to Dallas,

Texas, 511 miles from Galveston, at a total cost of over $5,000,000. This project was adopted after considerable discussion in Congress, and already $1,534,000 has been expended and three locks are now completed. The water is so low in this river at certain seasons that at one time it was seriously suggested that artesian wells be used for supplying enough water to overcome the waste due to lockages and evaporation. The commerce has never been important, and is now completely interrupted by the unusable condition of the river below the lowest lock. This river is another noteworthy example of the policy of providing facilities for river navigation long in advance of the necessities of commerce. One of the hoped-for results of river improvement in this instance was the regulation of rail rates from Dallas to Galveston, but legislation in Texas has already accomplished much in this direction, and the necessity for the very expensive work required is accordingly much less evident now.

PACIFIC COAST RIVERS.

On the Pacific Coast, the most important river, in point of commerce, is the Columbia River in Oregon and Washington. From its mouth in the Pacific Ocean up to the mouth of Willamette River, 98 miles, and thence up the Willamette River, 12 miles, to Portland, this waterway forms a very important artery of trade. Portland, by virtue of these rivers and their channels to the sea, becomes in reality a seaport, a fact that has been of inestimable value in the development of the enormous trade in grain and flour that has sprung up, largely with the Orient, and made Portland one of the first grain exporting cities of the country. The upper Columbia, together with the Snake River, for many years formed the only means of connection between the interior and Portland. In 1888, a line of railroad was opened along the south bank of the river and later, about 1910, a second line down the north bank connecting Spokane with Portland and Seattle was put in operation. These rail lines have reduced the importance of the river as a grain carrier; but the rule of bringing seagoing ships as far inland as possible will always maintain Portland as the main seaport of the Columbia, and insure, if not increase, the value of a

deep channel from Portland to the sea. The first project for this channel was to provide a 20-foot depth from Portland to Astoria at the mouth. This was adopted in 1877, and was easily secured with dikes and training walls, assisted by dredging. In 1891, the proposed depth was increased to 25 feet, and about $1,300,000 in all was spent in completing this project. In 1902, a systematic program of dredging, on a still larger scale, was adopted, and $2,639,000 was spent, in all, on this channel up to 1913. In 1912, the project was again extended, to provide for a depth of 30 feet at low water and a width of 300 feet from Portland to the head of the estuary at the ocean, and thence 26 feet over the bar in the sea. The estimated cost was $3,770,000. The extensive jetty work at the sea entrance has now resulted in a depth of 27 feet at low water on the bar, and, with a 7.5-foot tide, a draft of 27 feet can be taken to sea by observing the tides. The river channel near Portland will be provided with three dredges, a new 30-inch suction dredge having just been completed by the City of Portland. Two large suction dredges (24-inch) are now being built for the government, and on completion there will be six large suction dredges at work on the river channels between Portland and the sea. This method is mainly relied on to secure and maintain the proposed depth of 30 feet, but contracting dikes are used at localities wherever they are found useful. Already, 22% of the work has been done. Commerce on this part of the Columbia River has increased steadily of recent years, and in 1912 amounted to 6,840,659 tons, valued at $85,961,745. The main items are grain, lumber, coal and dairy products. The commerce within recent years is as follows, by five-year periods:

1890	1,416,311 tons	1905	3,259,958 tons
1895	1,347,155 "	1910	7,834,273 "
1900	1,489,708 "	1912	6,840,659 "

In the Columbia River above the mouth of the Willamette River there are still many difficult obstructions, for the character of the river changes abruptly at the Cascade Rapids, about 100 miles above Portland. Here the river has cut its way down several thousand feet through the Cascade Mountains in a narrow and precipitous rocky gorge. To overcome

these rapids, a canal one-half mile long was built over twenty years ago, and opened to navigation in 1896. A double lock, each part of which is 462 feet long, 92 feet wide, with a depth of 8 feet on the sills and with a total lift of 24 feet, was built and has been maintained in operation since then. It has cost $3,825,000. River commerce has not developed in this upper part of the river as was originally expected, as will be seen from the statistics of recent five-year intervals. Until the

Fig. 16. The upper end of the Dalles-Celilo Canal, Columbia River, Oregon. Side walls of concrete carry the canal trunk around Celilo Falls.

channels in the upper river are made safer, a great increase could hardly be expected; and in the meantime the railroads have been completed and have taken over nearly all the increase in commerce of this prosperous region. In 1900, the commerce was 17,710 tons; in 1905, 35,166 tons; 1910, 32,794 tons; and 1913, 33,219 tons.

About 90 miles above the Cascades are the Celilo Rapids, a complete bar at present to the use of the river at all stages. Here a canal about 9 miles long is now being built with four

locks, each 300 feet long, 45 feet wide and 7 feet deep over the sills, to overcome a total lift of 81 feet (Figs. 16 and 17). This canal is being cut for part of its length through the basaltic rock of the locality (Fig. 18), and the design of locks is somewhat unusual in the details of the walls and gates. The estimated cost of the work is $4,845,000, of which over

Fig. 17. A section of the Dalles-Celilo Canal, Columbia River, Oregon, showing concrete lining in the section through sand.

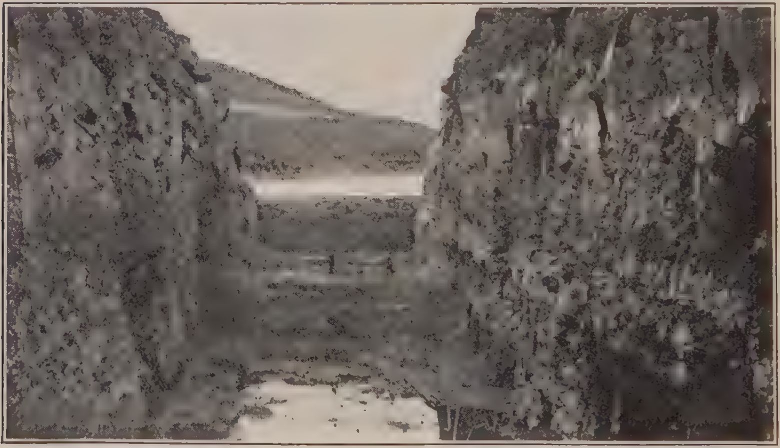

Fig. 18. Excavation for a lock in the basaltic rock for the Dalles-Celilo Canal, Columbia River, Oregon.

$3,000,000 has already been spent and the work is now more than two thirds completed. The original project, now discarded, provided for a boat railway on which vessels were to be raised about 10 feet above the water at the upper end and dropped 90 feet at the lower end, after being transported about 9 miles overland. The light construction of the vessels of the Columbia River and the difficulty in building a car that would be suitable for safely carrying vessels over the vertical and horizontal curves which were indispensable to the plan were some of the strong reasons which caused the abandonment of this project.

Whether the commerce of the upper Columbia River, together with that of the Snake, will ever warrant the high cost of this canal and that at the Cascades, is a problem that will require many years in the future for solution. It was recommended that a portage road be built around the Celilo Rapids before commencing on the canal, in order to determine the volume and character of the commerce which might develop. This portage road could be built for about one tenth of the cost of the canal, and could be used as a construction road if the canal were ever built. The pressure for a canal, however, was so urgent that funds were finally provided without considering the portage road favorably, and the canal work is now well under way. The increase in the productive capacity of the rich agricultural lands of eastern Washington and Oregon and western Idaho is fully meeting the early expectations, but it remains to be seen how much the river will be used in the future as a line of commerce in competition with two parallel lines of railroads in the same valley.

At the mouth of the Columbia is a notable instance of river work, which, for the boldness of its undertaking and the success attending the work, has been widely studied and frequently commented on by river engineers. The training of the river currents over the bar in the ocean, including not only the tidal currents, but also those arising from the natural discharge of the river, are so directed as to scour greater depths, and the restriction of all useless side currents and the shelter for the channel thus created are all accomplished by double jetties of rip-rap so placed as to direct the dynamic effect of

these currents at a particular place on the bar. Originally, bar depths were from 19 to 21 feet, but already the controlling depth is 27 feet. The south jetty is to be 7 miles long, extended into the open sea where storms are of great violence and often of long duration. The north jetty is to be two and one-half miles long. The total sum expended has been nearly $9,000,000, including the cost for maintenance. The south jetty has been completed, and the north jetty has been started. A depth of 40 feet over the bar is expected when the work is nearer completion.

The Sacramento is the principal river in California. The San Joaquin River, which joins with the Sacramento at the head of Suisun Bay, is used for navigation in the tidal portion up as far as the Stockton Channel, about 45 miles, but above this point is not extensively used. The Sacramento is about 350 miles long, but the uppermost 90 miles of the river is torrential in character and not used for navigation. It is subject to numerous floods, which inundate several hundred thousand acres in the center of the state nearly every spring. Its low water discharge is about 8,000 cubic feet per second, and at high water it has reached 640,000 cubic feet per second. Formerly, the plan of channel development provided for securing 7-foot depth at low water up to Sacramento City, about 61 miles from Suisun Bay. In this bay the depths up to the mouth of the Sacramento are 14 feet and over. The project also provides for a four-foot depth from Sacramento to Colusa, 90 miles, and two feet to Red Bluff, about 110 miles further. On this project, over $740,000 has been spent, and the projected depths have been secured and maintained for many years. The Sacramento River and the Feather, a tributary, were very much subject, a few years ago, to deposits washed down from the extensive placer mining regions of the upper Feather, Yuba, and Bear Rivers, and a Commission of Army Engineers was organized in 1891 to protect the stream. Debris conditions are now materially improved in the placer mining regions owing to the restrictions imposed. This Commission, in the performance of its functions, has recently proposed a plan for combining the control of floods, the impounding of mining debris and the betterment of the navigation channels in a single

project which has been adopted by the State of California and favorably reported by the committees of Congress having this legislation in charge. These committees have accepted the plan in principle, that the United States and the State of California should share the expenses equally. Legislation by Congress on this subject was unfortunately interrupted by the total failure of the 1914 bill. This is a very unusual example of an excellent coordination of the various features of river work, and may be held up as an example to be followed on other streams. The estimated cost of the project is about $11,000,000, of which the State of California is to pay one half and furnish the land necessary for levees and other works. The management of the construction work is to be under the direction of the army engineers of the government, and on completion the whole is to be turned over to the State for maintenance. Flood control on the one hand, involving the reclamation of thousands of acres of valuable agriculture land from spring inundations, and channel development on the other are so related, and the additional need of restricting mining debris are all so intimately connected, that it made it essential to put one organization in charge of all the related activities, in order to secure economy in operation. This new project, approved in 1910, includes the excavation of river channels by dredging, the construction of levees, using the excavated material, in order to control high-water stages, and further involves the proper gauging of the river widths to prevent choking in the lower reaches. The river mouth is also to be widened and straightened. Mining debris is to be impounded, as far as possible, at the site of the mines. Already, two large 20-inch suction dredges are at work on this project, which promises unusual results and widespread benefit. Commerce on the Sacramento amounted to 249,105 tons in 1890; 419,647 tons in 1895; 484,806 tons in 1900; 353,164 tons in 1905; 425,000 tons in 1910; and 477,292 tons in 1913.

ATLANTIC COAST RIVERS.

None of the rivers on the east coast of New England present any specially interesting or novel features in point of channel development or amount of commerce carried, except

that there are a number of rivers entering bays, like the Mystic in Boston Harbor, which for a few miles partake of the character of tidal estuaries or harbors for important cities and are the means of handling large quantities of freight, mainly coal. In general, this commerce is increasing; but this kind of stream is in a separate class, in fact it is the only class which the records show to be materially increasing in commerce. Most of these streams have depths of 20 feet or over, and furnish ship channels of considerable importance. In general, the tendencies on the other rivers in this vicinity are to a decrease in commerce.

The Mystic River was originally 14 feet deep in its lower portion, of about two miles, but was increased in depth to 25 feet by the provisions of the project of 1899, at a cost of $136,000. The latest project, that of 1910, provides for an increase to 30 feet depth, at an additional cost of $172,000. The commerce of the river was originally incorporated in that of Boston Harbor, but in 1905 was 2,841,007 tons; 1910, 3,245,630 tons; and in 1912, 3,671,242 tons, valued at $16,000,000, 90% of which was coal. This harbor is fairly representative of those of its kind in this region and shows present tendencies.

Providence River is only about 8 miles long, but is an estuary of much importance. Its original channel depth of less than 9 feet is now deepened to 25 feet, and the area of deep anchorage enormously increased. The latest projects, those of 1910 to 1913, provide for a 30-foot depth of channel and a deepening of the anchorages, at a total estimated cost of about $1,500,000. A new restriction, however, is now included; that before work can be begun, the State of Rhode Island and City of Providence shall complete their proposed public terminals and other harbor works, at a cost of $2,000,000. Already the government has spent $1,324,000 on previous work. The commerce in 1895 was 1,643,700 tons; 1900, 2,823,308 tons; 1905, 2,259,173 tons; 1910, 3,814,982 tons; 1913, 4,585,364 tons. Commerce by water is chiefly coal. The requirements of the U. S. Government, that local interests shall share in the expense of harbor work, is a new and increasing feature of great promise.

The Hudson was one of the earliest rivers of the country

to be improved by the Government. Work began even before 1822 by the State of New York, at which time the Erie Canal was opened, and in 1823 the Erie and Champlain both emptied into the pool created by the state dam at Troy, finished about that year. In the beginning, the river was shallow in places, and not over 4-foot depth existed over some shoals. Work by the United States began in 1834. At present, a channel exists that affords a 39-foot draft from the sea up through the harbor of New York to the city wharves in the lower portion of the river, and from there, 30-foot depth can be found upstream for 93 miles and 24-foot for 24 miles further. The upper stretch of 39 miles is limited to 9 feet draft except between Albany and New Baltimore where 11 feet is available. This work has been completed many years and has cost about 5½ millions of dollars. The newest project, that of 1910, provides for 12-foot depth in the upper 39 miles, necessitating a new lock and dam near the old State dam and considerable open channel work. This dam, with the deepening in the old channel as far down as Waterford, is estimated to cost $5,186,064. About one fifth of this work is now done. Commerce in the last two years has declined, but this is ascribed to the uncertainty of the effect of the New Erie Canal and the abandonment of the river ice houses. The commerce in 1900 was 5,070,800 tons; 1905, 3,513,545 tons; 1910, 5,033,360 tons; and 1912, 3,045,136 tons, valued at $172,107,996.

Harlem River and Spuyten Duyvil Creek together form a waterway eight and one-half miles long, connecting Long Island Sound with Hudson River along a line north of New York City. The deepening of this waterway has resulted in a new channel which enables freight to be brought by water to a very large manufacturing region in upper New York City. Its commerce has increased very markedly of late years. Originally, the channel was narrow and crooked and only 4 to 6 feet deep. The project of 1878 provided for a channel 15 feet deep and 350 feet wide, at an estimated cost of $2,100,000. The proposed width has now been increased to 400 feet and the project has been further amplified from time to time, and the estimate finally increased to $3,500,000. Up to 1913, $1,683,000 had been spent, and about 44% of the work done. Full depths are not

yet available at Macomb's Dam and near East 210th Street, but elsewhere the project is practically done.

Commerce in	1893	was	3,384,466	tons	
	1895	"	7,533,594	"	valued at $203,707,376
	1900	"	4,474,687	"	
	1905	"	9,998,021	"	" " 270,210,309
	1910	"	12,822,885	"	
	1912	"	15,376,742	"	" " 742,503,048

This river may be said to have reached the third stage of development, before mentioned, where the congested condition of traffic has provided so much commerce that a large share necessarily falls to the water lines. Arthur Kill is another stream emptying into New York Harbor of similar nature. Its commerce in 1912 amounted to 30,525,094 tons, valued at $515,437,656.

Delaware River is 315 miles long, but the portion from Philadelphia to Delaware Bay, 101 miles, is the part most used for navigation. In this lower portion the original depth of 17 feet has been increased materially, and the width of the channel nearly doubled. The first formal project, adopted in 1888, provided for a depth of 26 feet from Philadelphia to Delaware Bay, and a width of 600 feet. This project was completed in 1898. In 1899, it was planned to secure a depth of 30 feet. In all, $10,176,000 has been expended on this part of the river since 1834—on these two projects and on former work. In 1910, the project was further amplified to provide a depth of 35 feet, and a channel 800 feet wide in the straight parts and 1,000 feet wide at the bends, all at an estimated cost of $10,920,000. This work involves the removal of 53,000 cubic yards of rock and over 73,000,000 cubic yards of soft dredging. Two suction dredges are now constantly at work on the new project. About $2,000,000 has been spent thus far, and the new work about one eighth completed. In recent years, the commerce has shown a healthy increase.

In 1890	it	was	11,356,270	tons	
1895	"	"	18,626,853	"	
1900	"	"	21,910,232	"	
1905	"	"	24,383,571	"	valued at $1,612,847,499
1910	"	"	24,677,671	"	" " 1,327,869,862
1912	"	"	26,267,335	"	" " 1,235,106,621

By far the largest item of this commerce is coal. It will be seen from these figures how important a part in the development of this enormous traffic the channel development has played.

The St. Johns River in Florida is another example of increasing traffic, fostered and encouraged by well-chosen river work. This stream was originally closed at its mouth by a bar on the ocean, over which there was only 5 to 7 feet depth at low water. By means of two jetties, supplemented by dredging, these depths have now been permanently increased to 25 feet at low water. The upper river, also, was originally interrupted by shoals of about 11 feet depth. In 1879, a project was adopted for a channel having a depth of 15 feet from Jacksonville to the sea, 27.5 miles. In 1892, it was found that the channel over the bar had been fixed in position by jetties and the depth increased, by that time, to 13 feet at low water, and a new project for 18 feet depth of channel was thereupon adopted before the earlier work had been completed. This latter project was completed in 1894. In 1896, the proposed depth of 24 feet at low water and width of 300 feet was approved and work was undertaken. This project was practically completed in 1910, when the present project of a 30-foot depth of channel was adopted. The newly proposed width is 300 feet in straight reaches and 600 feet at bends. On the earlier projects, $4,000,000 has been expended, and on the present plan, $1,266,912, and work is about half completed. This new channel has been very effective in affording cheaper lines for freight destined for northern ports and affects a large and prosperous area. Commerce has increased at a healthy rate and has justified the original estimates of growth, and apparently warranted the expenditures necessary.

The commerce in	1890	was	746,895	tons
	1895	"	241,907	"
	1900	"	649,221	"
	1905	"	1,000,316	"
	1910	"	2,105,820	"
	1912	"	2,204,794	tons, valued at $67,877,603

The success attending the opening of the mouth of this river in the Atlantic Ocean has been very marked. This river, together with the Columbia River and several others on the Atlantic and

Pacific Coasts, furnish examples of a distinctly courageous treatment of river mouths in the open sea. This method of applying twin jetties of rip-rap to bar harbors has now been well tried, and is accepted as an approved method of overcoming the obstruction caused by streams and tides at the mouths of rivers emptying into tidal seas.

GENERAL OBSERVATIONS.

In conclusion, it might be well to summarize some of the more noticeable tendencies in our interior natural waterways. First, one is struck at once with the enormous increase in the commerce of the Great Lakes between the western end of Lake Superior and the harbors of northern Ohio. In spite of all efforts, it seems almost impossible to maintain facilities much in advance of the needs of navigation. New and larger locks at the "Soo", new and deeper channels in Lake Huron are scarcely complete before deeper boats and more perfect terminal facilities make these waterways inadequate to the new demands. Notwithstanding the several months of idleness in the winter time when ice stops all navigation, the tonnage carried has increased year by year until it has been necessary to have separate channels for upbound from those used for downbound vessels and much more than double the lock capacity at St. Marys Rapids. The new and extensive projects for the accommodation of this traffic seem well justified.

Second, it seems deeply disappointing to see nearly all of the rivers of the Mississippi Valley either conspicuously declining in traffic or, in a few cases, holding their own with much difficulty. Notwithstanding the adoption of the best type of locks and movable dams, the most modern and effective open river work and the aid afforded by the government in improving the shallow-draft river steamboats; notwithstanding huge appropriations and extensive work of the highest engineering skill; notwithstanding the enormous increase within recent years in every branch of industry in this wide area, these rivers have declined in usefulness and importance; their freight has been extensively taken over by the railroads of this region; boating has dwindled as a business until the Mississippi River itself, a stream unequalled in possibilities, now flows idly to the

Gulf with only a small fraction of its former traffic. A marked diminution in appropriations for all rivers in this valley may be expected in the next few years. Already, signs are pointing to a more careful scrutiny of all work proposed in this region, and to a closer study into the probable benefit to the country as a whole of the large expenditures now being made annually.

Third, it is gratifying to note the healthy growth in the commerce of many of those coastal rivers which flow into seaports and enable deep-draft vessels to reach interior cities from the sea. Coal is an important item of their cargoes, and the lowering of the cost of this commodity is widespread in benefit. This character of channel development may be expected to continue to increase in capacity as long as an increase in traffic and saving in cost of transportation can be shown. Here, too, it seems probable that new work will more than ever need to have conclusive reasons given for its adoption by the government, before it can be undertaken.

Fourth, the success in the application of the lessons learned by experience in the jetty system of deepening the entrances to rivers from the sea has been very satisfactory. The Columbia River, the Mississippi River, and the St. Johns River are all examples of difficult kinds of engineering in which Americans have been pioneers, and the results are exceptionally satisfactory. Nowhere in the world have such daring attempts been made, and nowhere have results been more effective. The great perfection of the suction dredge has so reduced the cost of channel excavation, that now new channels are being deepened that before were too expensive and hazardous for even a conclusive trial, as in the case of the Ambrose Channel entrance to New York Harbor. This method of deepening, so useful in interior channels, has also been widely adopted as an auxiliary to jetty work, and is now generally recognized as a necessary aid in bar improvement. Although dredging in some harbors, as at the mouth of the Columbia, has not demonstrated its value in this place; still the results at Galveston, Mississippi River, St. Johns River and New York, and nearly all ports on the Atlantic and Gulf Coasts have been conclusive.

Fifth, the recent, but nevertheless desirable, combination of several governmental activities in river work under a single

head has been again recognized in the Sacramento River. For some years, the control of floods on the Mississippi by levees has been carried on by a cooperation of the state and Federal forces, under a tacit agreement never specifically stated in the law. On the Sacramento, we now find reclamation of flooded areas, control of floods, deepening of channels for navigation, and the exclusion of mining debris all proposed under the Federal management by law. In this work the state assists by paying one half of the expense, by donating the land needed for levees and by taking over the work and maintaining it after completion. The share that the locality should pay toward a project of this character must depend mainly on the distribution of the benefit, and is debatable; but that the execution of such work should be handled as a single unit by the government seems beyond argument. It is gratifying to note the acceptance of this principle.

Sixth, there is a recent and growing tendency to conserve the energy of our navigable rivers by private enterprise in order to develop the electric power now being wasted. This requires a cooperation between the government, on the one hand, and the private interests which build the necessary plant, on the other. It is seldom that a dam for the creation of electric power is just what the needs of navigation require, so there must be some adjustment or balance between the private and public requirements. Usually, the company builds the dam at its own expense, and sometimes the lock in addition, and is often restricted as to the height of dam and location. The present power dam in the Mississippi River at Keokuk is completed; that at Hales Bar in the Tennessee is nearly finished; and two are under construction, one on the Warrior and one on the Coosa River in Northern Alabama. It is too soon to say whether these ventures will prove to be commercial successes. It is encouraging to find that some reasonable basis can be found on which the power of a navigable stream can be conserved, whenever it has a commercial value.

Seventh, the deepening of the channel of the Providence River, which has recently been made contingent on the construction by the City of Providence and the State of Rhode Island of public port and terminal facilities at their own ex-

pense, illustrates a comparatively new and very important tendency. It is more than ever expected of late that the localities benefited by government projects will share in the expense of the work, as well as in the benefits. Portland, Oregon, has undertaken to maintain at its own expense the upper part of the channel from Portland to the sea. The jetties at Suislaw River mouth, in Oregon, will be paid for largely by the locality. The Sacramento River improvement is to be one half paid for by the State of California, and other assistance is to be rendered. A public wharf was required to be donated by the town of Burnside on the upper Cumberland River before Lock 21 would be completed. Many other instances might be stated, so that this principle of the localities sharing in the expense of river work is now well established. In this way the earnestness of the communities urging government work can be easily tested, and the public oftentimes assured that the channels when completed are not to be the sources of undue profit to the private owners of the only easily accessible landings.

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DISCUSSION

Gen. Chittenden.

Gen. H. M. Chittenden,* M. Am. Soc. C. E. (by letter), called attention to a rather unusual river and harbor improvement in the city of Seattle, Washington, not mentioned in Col. Harts' paper. The Seattle improvement is a canal connecting Puget Sound, a great inland tidal estuary, with two fresh-water lakes of a combined area of almost 40 square miles and an aggregate shore-line of nearly 100 miles. The lake surface will stand about 25 feet above extreme low-tide and about 7 feet above extreme high-tide. Connection with the Sound is by means of two locks in parallel (only one lift), one lock being for large vessels and log rafts and the other for small craft. The large lock is 825 feet long between quoins, 80 feet wide and 36 feet over sills; and the small lock, 150 feet long, 30 feet wide and 12 feet deep over sills.

The county of King, in which Seattle is located, is contributing almost half the total cost, including the right-of-way, the channel excavation above the locks and the bridges. The United States Government is providing the funds for the locks and for the excavation of the tidal portion of the channel; the total cost of the work is about $5,000,000.

Nearly all portions of the lakes have a depth sufficient for the heaviest shipping. Owing to the exceptionally fine tidal harbor in Elliott Bay, the fresh-water harbor will not be used for deep-sea shipping to the extent that it would be in a port like Los Angeles. However, the lakes surely will develop into important use for mosquito-boat traffic, for vessels going to and from industrial plants, for the distribution of local products, and as an ideal harbor of refuge for vessels of every description when temporarily out of commission.

An interesting feature of the work is the threatened development, in aggravated form, of the difficulty experienced on the Panama Canal from the ingress of salt water to the pool above the locks. There being but one lock at Seattle, as against three at Panama, the ingress of salt water promises to be more serious and special means are being taken to prevent it.

In regard to the decline of commerce on inland rivers above such points as may be reached direct by deep-sea vessels, mentioned by Colonel Harts, the existing condition brought about by steam-electric railroads appears to be natural and inevitable. Very rarely do streams flow in the most favorable direction for traffic; they reach directly only a very limited territory; in the North they are frozen up several months of the year; and flood and drought produce ever recurring difficulties in their utilization. The railway is free of these drawbacks; it penetrates all parts of a territory; it goes where the traffic wants to go, and it operates the year round. These advantages offset, and frequently more than offset, the greater economy in water carriage.

Also, hitherto there has been a general lack of suitable terminal facilities for water carriage. That difficulty might be overcome grad-

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Gen. Chittenden.

ually; but not so readily could proper transportation routes be established to and from such terminals, so as to give a really efficient water service to the interior country.

To these drawbacks of water carriage must be added the historical feature. This is a young country, and by far the greater part of its development has occurred since the advent of the railroad and has been controlled by railroad expansion. In old countries, where water-courses have long been the chief avenue of trade, like the Valley of the Rhine, the towns developed mainly along the rivers and the coming of the railway found conditions already established beyond the possibility of radical change. In the United States this is not true to anything like the same extent, though many of the older towns began their existence on rivers and because of the rivers; railroads have led to the development of a vast number of towns without regard to watercourses. Thus there has been in the United States less dependence upon watercourses to begin with, and the influence of established custom in maintaining such dependence has been absent.

General Chittenden sees little upon which to base an expectation of the revival of the commercial use of our rivers above what may be called their estuary portions; there will be isolated exceptions, but the rule of gradual decline of traffic will be general. There is great doubt of the wisdom of such works as the Illinois and Mississippi Canal, the proposed Lakes to Gulf Waterway, the canal from the head of Lake Michigan to Lake Erie, that from Lake Erie to the Ohio (unless possibly one terminating near Pittsburgh), any radical program of channel enlargement of the Mississippi River and its tributaries, or any expectation of great use of the new Columbia River route. This view will appear rank heresy to many, but it is sustained by the irresistible logic of facts as disclosed by the records of the past.

Paper No. 30

FLOOD CONTROL.

With Particular Reference to Conditions in the United States.

By

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PREFATORY NOTE.

The wide scope of the subject and the limit of space assigned have necessitated an abbreviated style of treatment not altogether in keeping with agreeable literary form.

No attempt has been made to comply with the request of the managers of the Congress to compile a bibliography of the subject, for the reason that, if at all complete, it would be longer than the paper itself. Even a citation of the leading authorities consulted on the Mississippi problem alone would require several pages. It is understood, moreover, that the Morgan Engineering Company, which is working out the Dayton problem, has about ready for publication what will undoubtedly be the most complete bibliography of flood literature extant. There is also a bibliography of flood literature of 35 pages in the report of the Pittsburg Flood Commission elsewhere referred to (1912) ; and a similar compilation of 48 pages in the Monthly Bulletin of July, 1908, Carnegie Library, Pittsburg. Duplication of work, in view of these facts, seems unwise. The author should state, however, that as far as his paper is concerned, he has supplemented published data by extensive correspondence touching every feature discussed therein.

Material assistance has been received from Prof. C. W. Harris of the Engineering Department of the State University

of Washington, and the drawings have been prepared by Mr. F. M. Warner of the same staff.

It is suggested that those who peruse the paper consult first the preliminary table of "Names, Abbreviations and Equivalents", as the English abbreviations are much used throughout. The "Equivalents" may be of assistance to foreign engineers accustomed to the use of the metric system.

NAMES, ABBREVIATIONS AND EQUIVALENTS OF CERTAIN UNIT QUANTITIES FREQUENTLY USED IN THIS PAPER.

(British and Metric Systems.)

Names and Abbreviations.

English Name	English Abbreviation	Metric Name	Metric Abbreviation
Inch	in	Centimetre	Cen
Foot	ft	Metre	M
Square foot	sqf	Square metre	sqM
Acre	Acre	Hectare	Hectare
Mile	mi	Kilometre	K
Square mile	sqm	Square kilometre	sqK
Cubic foot	cf	Cubic metre	cM
Cubic yard	cyd	Cubic metre	cM
Cubic feet per second (or second feet)	cfs	Cubic metre per second	cMs
Cubic feet per second (or second feet) per square mile	cfsm	Cubic metre per second per square kilometre	cMsK

Equivalents.

British-Metric			Metric-British		
1 in	2.5400	Cen	1 Cen	0.3937	in
1 ft	0.3048	M	1 M	3.2809	f
1 sqf	0.0929	sqM	1 sqM	10.7641	sqf
1 acre	0.4047	Hectare	1 Hectare	2.4711	acres
1 mi	1.6093	K	1 K	0.6214	mi
1 sqm	2.5894	sqK	1 sqK	0.3861	sqm
1 cf	0.0283	cM	1 cM	35.3156	cf
1 cyd	0.7645	cM	1 cM	1.3080	cyd
1 cfs	0.0283	cMs	1 cMs	35.3156	cfs
1 cfsm	0.0109	cMsK	1 cMsK	91.4558	cfsm

PART I.

GENERAL PRINCIPLES.

I. ORIGIN OF FLOODS.

(1) Definition. Floods are overflows of water beyond the normal margins of beds or channels. Contiguous bottom lands become occupied by human activities and when overflow seriously interferes with such occupancy, it becomes, in man's estimation, a "calamity" or "visitation", though a perfectly normal proceeding in Nature.

(2) Varieties of Floods. The most common variety of floods, and the only one considered at length in this paper, is that due to lack of capacity in channels for the duty imposed upon them. Fortuitous occurrences, like the storm wave at Galveston in 1900, the Lisbon earthquake wave in 1755, glacier floods, dam failures, etc., are not subject to rule or intelligent control and will not be considered here.

(3) Ice Gorges. Ice gorges, as a cause of floods, should perhaps receive passing mention. They are of common occurrence on all streams subject to winter conditions, but are most frequent and severe on streams flowing north, particularly those of extreme northern latitudes. On such streams the sources break up first and the ice jams up on the frozen river below, sometimes inundating vast areas, though generally with little damage because of the absence of settlement. Streams of lower latitudes, like the Missouri River, are much subject to gorges of short duration. The Danube is the most prominent example of a river on which extensive works have been executed to control overflow from this cause, though much is done on all ice-bearing streams to prevent damage to structures by impact of the ice itself.

(4) Flood Stage. In further development of the definition in Paragraph 1, it may be said that "high water" becomes "flood" when overflow of banks begins and damage is imminent. This point is known in flood service nomenclature as the "flood stage", and is stated in terms of gauge height at important points on the principal streams.

(5) Origin of Floods. Floods originate in precipitation—a fact which is of interest in the flood problem, not because man has any control of this origin, but because knowledge of the occurrence furnishes some assistance in controlling results. In the main, man has to accept the storm when and where it comes and confine his efforts to dealing with the consequences.

II. RUNOFF.

(6) Beginning of Flood Problem. The flood problem begins with runoff, that is, when water from precipitation begins to flow to and along the channels by which it is conducted to lower altitudes. The percentage of precipitation which reaches stream channels varies all the way from nothing to 100 per cent, and is governed by many influences, such as permeability of soil; vegetable and other cover; slope; drainage; saturation of ground; frost; snow; reservoirs; wind; intensity of rainfall; etc.

(7) Detention, Evaporation, Runoff. Precipitation flows away in surface streams or disappears into the air, except that small portion which reaches the sea or interior basins through underground channels. The fact that a large percentage soaks into the ground has led to a three-fold division—percolation, evaporation and runoff; though it is manifest that the first is eventually disposed of mainly by one or both of the other two processes. But as water of percolation is more or less delayed in its final disposition, it is abstracted from the runoff of the storm from which it is derived. It is therefore a direct and separate factor in flood control and may properly be placed in a class by itself. The term "detention", applied to it by Prof. D. W. Mead, seems well chosen.

(8) Geologic Formation. The character of the ground is of high importance in flood control. Soils are classed by the French as permeable and impermeable. Glacial drift, gravel wash from hills, porous or broken rock are examples of the first class; rock in situ, clay, etc., of the second. Impermeable soils are usually covered with a blanket of earth of high absorptive capacity. Frost produces temporary impermeability. Pavements, roofs, etc., produce complete impermeability over limited areas, and the rate of runoff in cities is uniformly high.

(9) Permeable formations are vast storage basins. Streams in them rise and fall slowly and low water flow is longer sustained. Impermeable soils shed water quickly, streams are more "flashy", and flood effects more quickly developed. In times of great flood, permeable soils become saturated and the rate of runoff may approach that on impermeable soils. Permeability may thus, at the critical moment, exert little effect.

(10) Saturation. A saturated soil can hold no more water. The effect of the ground in moderating floods depends upon its condition when storms arrive. Summer storms find the soil more or less dried out, and rarely produce maximum flood effects, even though of great intensity. High temperature and the intermittent character of storms prevent saturation, and ground storage is always available at such times. Rain in the Pittsburg district is heaviest in July, but floods are rare in that month. Intensity of rainfall influences the effect of ground storage. If the water comes too fast, the storage may fail to materialize fully for lack of time.

(11) Temperature. Temperature exerts a powerful influence upon floods both in moderating and intensifying them. Evaporation varies with temperature. Direct evaporation is never swift enough to moderate the immediate effect of heavy downpours. Its effect is cumulative in periods before storms by abstracting moisture from the ground. This results from direct evaporation and from absorption of moisture in vegetation, partly in growth, partly in transpiration into the air. Thus ground storage develops rapidly in summer time and heavy rains are quickly absorbed. This explains why great floods in northern climates usually occur during periods of cold weather—if not too cold.

(12) High temperature intensifies floods which result in part from snow melting. Sometimes this agency determines the character of a flood.

(13) Slope. Slope is the inclination of ground surface or channel bed to the horizontal. There can be no runoff without some slope, though the slope may be in the water surface only. Increase of slope increases the total runoff as well as the rate by diminishing the time for water to soak in or be evaporated. More of it reaches streams on steep than on flat slopes, but this

difference diminishes with impermeability or saturation of the flat slopes. Water once in channels is carried more rapidly to lower altitudes as channel slopes are steeper. The common belief that steepness of slope increases flood effects is probably largely fallacious. While freshets, as already stated, develop rapidly, steep channels are generally best fitted of any to carry them within banks. Since floods in lower altitudes are mainly results of tributary combination, quick arrival from a particular tributary is as likely to work against as in favor of a combination. (Paragraph 48.)

(14) Wind. Rapid change of air increases evaporation, if the air is not already fully moisture-laden, and may thus slightly affect floods. With heavy and long continued rains over wide areas, this effect is probably very little. Dry winds coming into storm areas, as often happens in the arid regions, may drink up precipitation with great rapidity. How far winds affect the distribution of storms, and thus indirectly runoff, it is impossible to say.

(15) Snow. While snow remains solid it forms a perfect reservoir. If high temperature comes in form of sun action, melting takes place in the day time and ceases at night and there is a diurnal rise and fall, but no flood. When, however, high temperature pervades the atmosphere night and day, aided, as is generally the case, by rain, melting proceeds with great rapidity and disaster may be looked for. The precipitation of two or more storms is thus concentrated into a single runoff. Snow melting is intensified by the absorptive quality of snow which at first acts as a sponge, absorbing the water of its own melting until saturation is reached, when liquefaction may follow with great suddenness.

(16) Drainage. Artificial drainage operates both to increase and restrain floods. Surface drainage of all kinds facilitates runoff and hastens water to the streams. Whether the effect of this be to increase or diminish floods on lower courses depends on fortuitous combinations of arrivals from tributaries. In one respect drainage diminishes floods. Both surface and underground drainage tend to dry out the soil and thus increase its absorptive capacity, so that when storms come there is more ground storage. In case of soils naturally swampy and

wet this effect may be considerable. French engineers make particular note of it.

III. VEGETABLE COVER—FORESTS.

(17) Popular Belief. Popular belief in the efficacy of forests to restrain floods is well-nigh universal. Forest preservation and re-forestation are therefore generally regarded as effective measures of flood relief. The belief is important, even if not true, because of its influence upon legislation. It is necessary, therefore, to examine it in some detail.

(18) Forest Theory. The theory of forest action on runoff is that the forest mulch has great absorptive capacity and therefore acts as a reservoir. This, with obstacles to runoff, such as fallen trees and forest litter, retains the water and gives it a chance to soak into the ground—a process which, it is alleged, is further facilitated by the greater porosity of soil due to inter-penetration of roots. The forest thus delays the runoff and mitigates the intensity of floods. For reasons stated below, these assumed effects, so far, at least, as great floods are concerned, are almost wholly imaginary.

(19) Forest Soil and Cover. That forest mulch has a high and quick absorptive capacity is true, but the extent of its influence is greatly exaggerated in the popular belief. In forests under culture, fallen timber, limbs and debris are kept cleared up, both for fuel and to lessen fire danger. In virgin forest, before logging operations begin, channels through and under debris develop from long use. The retentive effect of debris is undoubtedly greatest in the interval between felling and clearing off the land. The ground in the forest is more compact than in the open, especially where large trees stand, the very stability of which compacts the soil beneath them until it is almost impermeable. The phenomenon of upturned tree roots demonstrates this. The aggregate percentage of such compacted areas in dense forests is large and the restraint upon permeability correspondingly great. Roots are not loose in the ground except in decay. In open country, under cultivation, stumps and roots are eradicated, the ground is broken up with the plow, and the soil near the surface is made more permeable than in its natural condition in the forest. Beyond a few feet

depth it is the same whatever the surface condition. Open country vegetation itself has great absorptive capacity. Experiments in France upon common lawn turf show a quick absorptive capacity of 25% of thickness. The common belief, therefore, in the greater permeability and absorptive capacity of the soil under forest cover seems not to be well founded.

(20) Reservoir Effect of Forests. The storage of the forest mulch, whatever it may amount to, is wholly ineffectual even locally, in great floods, for the reason that it becomes exhausted before the crisis of the flood arrives. This was officially recognized by the chief of the forestry service in France in discussing the Paris flood of 1910. Even if there were some local restraint, its effect on floods further down the valley would be subject to all the uncertainties of tributary combination.

(21) Forests and Snow-Melting. Snow spread out in an even thin blanket will disappear more rapidly under the same conditions of temperature and rain than if concentrated in great heaps. Drifts always linger after snow has disappeared elsewhere. Forests, by breaking the wind, cause snow to deposit more evenly and prevent the formation of drifts. Sometimes snow hangs in great quantities on trees and this further increases exposure. Forests unfavorably affect runoff from melting in still another way. Shade prevents sun action and the early melting that takes place in the open. The snow blanket of the forest gradually compacts through slower melting and the sponge action referred to in Paragraph 15. Liquidation is thus delayed until the warm air and rains of late spring arrive by which time the snow blanket is saturated and turns into water with great rapidity. This action is very pronounced in the Rocky Mountain region, where spring floods come mainly from forests. On the Pacific Slope the action is somewhat different but even more effective. Snows, amounting to several feet, come in a short time and are often followed by warm winds, "chinooks", accompanied by heavy rains. The result is an almost torrential runoff. The streams of the northwest coast, though in the densest forests in the world, are subject to destructive floods. In the Sacramento Basin, the spring and winter storms produce greater unit runoff for the same

rainfall on the forest covered slopes of the Sierra, than on those of the open hills of the Coast Range.

(22) **Forests and Erosion.** The first effect of tree cutting, as elsewhere pointed out, is to add to soil protection. Erosion does not develop until cultivation begins, nor then, to dangerous extent, except on unstable soils exposed by injudicious operations. There are instances, as in the hydraulic mining districts of California, where erosion has been on such a scale as to destroy the natural regimen of streams. But such examples are very rare. Ordinary cultivation need not be injurious, while turf and small shrubbery protect as well as any forest cover. Newly plowed fields, ditches, highway and railroad cuts and fills, etc., undoubtedly increase erosion. But experience shows that streams are generally able to carry this increased burden, and it is quite impossible to establish that the flood carrying capacity of river channels is, to any appreciable degree, restricted from this cause, except in some unusual cases such as those cited above.*

(23) **Forests and Precipitation.** It is said that forests increase precipitation on account of their cooler status as compared with open country. This may possibly be true of intermittent summer showers. It certainly is not true of long, continual, flood-producing rains, particularly when the forest is quite as warm as outside. If it were true to any material extent, the effect would be to increase floods.

(24) **Forests, General Conclusions.** Stream records abundantly confirm the foregoing deductions and show that floods were as great when the country was covered with virgin forest as they are now; and that modern re-forested areas yield as large runoff as do similar areas of cleared land. It may be set down as a rule in dealing with flood problems, that no material assistance is to be derived from re-forestation. The great importance of this conclusion lies in the fact of an almost universal belief to the contrary. So long as this belief is strong enough to influence legislation, and so long as relief is looked for in this direction, so long will really practical measures suffer. Even if there were any substantial basis for the theory,

* It should be stated that, in Europe, public policy is everywhere in favor of forest cover on mountain slopes to prevent erosion.

the very necessities of human existence would make the remedy of no value. It will never be possible to give up more than about one-fourth of the land area to forests—a percentage actually less than that of timber land (virgin and regrowth) of the United States today east of the 96th meridian. Therefore, if the theory were correct—which it is not,—it would be impossible of application.

IV. STREAM CHANNELS.

(25) Definition. Some French writers apply the terms *lit mineur* and *lit majeur*, minor and major channels, to the ordinary channel within banks and the greater overflow channel extending across the bottoms, occupied only in times of flood. The distinction is a useful one, but equivalent English terms do not readily suggest themselves. For lack of something better, the terms normal channel and overflow channel will be used in this paper, though both are, strictly speaking, normal.

(26) Normal Channels. As soon as concentration of flow begins along a particular line, originally the bottom of a depression, erosion carves out a channel, and this by long use adapts itself more or less completely to the duty required of it. A prominent authority has said,—"The size of channels is approximately proportionate to the average discharge". (The writer would insert "high water" before "discharge".) This is the general belief, but the exceptions are so many and important as almost to overshadow the rule. It would be more correct to say that the size of the channel is not altogether determined by the ordinary flow; still less by ordinary floods, and very rarely by extreme floods. It is influenced also by the slope, character of bed, and the habit of stream as to suddenness of freshets and carriage of sediment. The resultant of all these conditions, dependent upon the predominance of any one, may be a channel that will carry the greatest known flood or one that will not carry one per cent of it. Few streams of considerable size possess throughout their length channels even approximately proportioned to their average flow, to say nothing of flood flow. In places, where deep gorges have been cut, the capacity within banks far exceeds any possible flood. In

other places, where streams find themselves in flat plains through which they wind in sinuous channels of little slope, their capacity, more likely than not, will be less than the average flow and only a mere fraction of the extreme flow. In swampy areas the channels may be practically lost. Again, in emerging from foothills, where the debris carried down swift slopes is dropped at the beginning of the flatter slopes and spreads out in fan-shaped areas called ''cones'', the channels may be completely lost and floods may wander at will wherever the caprice of the moment takes them. Eliminating these extreme cases, however, channels do, as a rule, possess capacity for the ordinary high water flow. While the exceptions themselves seem eccentricities, in reality they are not so, but normal results of the law by which flowing water seeks the path of least resistance.

(27) Channel Encroachment. The statement is constantly made, even in professional circles, that man is an active agent in producing floods through encroachment upon natural channels, by placing piers and other structures between banks, or by pushing out the banks themselves to gain more land. Like all general statements it is subject to strict limitations. Piers, properly built, extending well below scour, with all false work removed and the channel bed left free of solid obstructions, are slight obstacles to flow. A very small increase of head compensates by increased velocity for restriction of section, and danger of overflow from this cause is easily met. Only when piers act as nuclei for drift heaps do they become serious obstructions. Bank encroachment is a more important matter but even that has strong compensating effects. On most rivers the tendency of human occupancy is to improve carrying capacity. Drift dams are removed, irregularities of bank straightened, sharp bends cut off, and, in cities, banks are revetted or lined with walls,—all of which facilitates the flow. If to this be added the dredging of solid obstruction from channel beds and particularly the increase of section by the raising or leveeing of banks, it will be seen that the net tendency of human dealings with stream channels is to increase their carrying capacity. There are nevertheless specific examples of very serious encroachment and of disasters resulting therefrom—as,

for instance, the Kaw River, Kansas City, in the great flood of 1903. (See Paragraph 134.)

(28) Overflow Channels. A form of encroachment commonly overlooked pertains to overflow channels (see definition, Paragraph 25). Man assumes as of right to occupy the bottoms contiguous to normal channels, and when floods invade them according to their wont they are regarded as trespassers. Measures of ejectment—not always easily accomplished—greatly restrict the overflow channels and force upon normal channels a duty which they were not intended to perform.

V. THE FLOOD PROBLEM.

(29) Statement of Problem. Whatever the sum total of man's instrumentality in flood production, there can be no doubt that flood destructiveness in the United States is, for the time being, increasing. This is due, however, not to flood increase, but to increase of property affected by floods. For example, the greatest flood on record at the mouth of the Kaw River was in 1844 and did no damage of consequence. There was nothing there to destroy. The next greatest flood, two feet lower, was in 1903, and caused the loss of many lives and of thirty millions of property. Kansas City had been built in the path of the flood. It is an easy passage from this fact of increasing destruction to the assumption that floods are increasing. But while this assumption is probably erroneous, it is true that the flood problem is increasing both in importance and in difficulty. This is because of the growth of interests affected and the complications arising from increasing interference with natural conditions. Technically speaking, the flood problem has for its aim the elimination, partial or complete, of overflow channels. It is sought to accomplish this either by so reducing the flood runoff as to make overflow channels unnecessary, or by forcing extra work upon normal channels, or by a combination of both. The measures employed for these purposes may be classed under two heads—Flood Prevention and Flood Protection—one dealing with methods of preventing, or diminishing, the flood flow itself; the other with methods of protecting against floods when they actually develop. Apart from these two classes, and in a

degree pertaining to both, are those measures that are now being taken by all progressive governments to give warning of the approach and probable magnitude of floods. These will be considered first.

VI. FLOOD FORECASTS.

(30) Limit of Forecasts. Calamitous effects of natural visitations could be largely discounted if they could be foreseen for even a short time. Absence of this knowledge is the basis of the insurance business. In the matter of floods some slight success in forecasts has been achieved. The present state of progress in this field may be summarized as follows:

(a) Science has as yet discovered no means of controlling in the slightest degree the occurrence or intensity of storms.

(b) Prediction of storms consists more in forecasting their progress across the country after they begin to develop than their occurrence before they actually begin.

(c) Prediction of the runoff, particularly on the lower courses of large streams, has been reduced to considerable certainty. For example, on the lower Mississippi, flood heights can be foretold from one to three weeks. Near the sources of streams predictions are reliable for only twelve to twenty-four hours in advance.

(31) Method of Forecasts. The practical method of making flood forecasts is to establish throughout a watershed a sufficient number of rainfall and gauging stations to give accurate and instant knowledge of what is happening and also of conditions as to snow, frost, saturation, etc. Some of these stations are permanent; others are called into use only in emergency. In France, where the system has reached its highest development, the various stations are rated according to their purpose and importance and directions for making reports from less to more important stations and finally to the highest central authority are prepared beforehand with great detail. The method of determining from reports the probable course and magnitude of storms is almost entirely empirical, and is based upon many years' observations. By this system, approach and volume of floods is made known as far in advance as is humanly possible, and undoubtedly does immense service in

avoiding loss. Notice of even ordinary freshets is of great value to navigation and other uses of streams.

(32) The American System. The American system is modeled somewhat after that of France but is not yet developed with the minute elaboration found in the older country. Two methods are employed depending upon the locality considered. Near stream sources, only the "runoff" method is practicable. That is, predictions are based solely upon the reported rainfall, the condition of the ground and the runoff to be expected therefrom. Further down, where there are gauges, the "runoff" method is supplemented by prediction of the effect of rise or fall of gauge heights upon gauge heights below. This is the "gauge relations" method and is practically the only one used on the lower courses of the large rivers. Both methods are wholly empirical and apply, of course, to main stream and tributaries alike. The system increases in complexity, but at the same time in accuracy, with distance from the stream sources.

(33) Flood Warning Service. The United States Weather Bureau is in charge of the flood warning service, and is assisted by other departments. There are sixty-two district centres at regular Weather Bureau stations. Daily gauge readings are made at these stations and at as many subordinate stations as are deemed necessary. Besides these, there is a class of special rainfall stations near the sources of streams. The organization embraces one central office, (Washington), 62 district centres, 16 additional gauge stations (regular), 391 additional subordinate stations, and 138 additional rainfall stations. Gauge readings are made up at 8 A. M. daily, 75th Meridian time, and more frequently in great emergency. Predictions are prepared and issued from local district centres. The annual cost of the flood service is estimated at $80,000. It is considered that in the 1912 and 1913 floods alone, the service saved property, through timely warnings, to the extent of many millions of dollars. The details of the service are too elaborate for enumeration here.

(34) Police Measures. In France the organization and general scheme of action in times of flood are worked out in as much detail as those for the mobilization of an army. Local

authorities know beforehand what to do when notice of danger is served on them. Prompt enrollment of citizens in the work of protection, and enforcement of necessary measures of all sorts are definite government requirements. Little of that sort exists in America. Communities do not disturb themselves until disaster is upon them and then work on individual initiative instead of prearranged plan. There is much heroic sacrifice, but a great deal of wasted effort. Anything like the French system during the Ohio Valley floods of 1913 would have saved probably all the five hundred lives that were lost, as well as a great portion of the property. On the lower Mississippi, where constant recurrence of floods has developed a voluntary system of flood fighting, loss of life is rare, in most floods, and loss of property is greatly reduced from what it would be if left to unorganized action after the floods arrive. The adoption of definite plans of action by all communities subject to great floods is an imperative public duty.

VII. FLOOD PREVENTION.

(35) Reservoir Theory. Flood prevention, that is, a reduction of the stream flow which causes floods, is wholly a matter of reservoir action. Theoretically, reservoirs furnish the ideal solution of the flood problem. As the term (*re servare*, to hold back), indicates, the reservoir function is to collect runoff when it comes too rapidly, hold it for a time, and pay it out later as the channel can safely receive it. This function corrects a serious mal-adjustment of nature, so far as man's needs are concerned, by balancing excess and deficiency against each other, and eliminating in one operation the evils of both flood and drought. If the theory is susceptible of practical application, the flood problem has found its solution.

(36) Classification of Reservoirs. Reservoirs will here be considered under the following classification: (a) From the manner of their occurrence or creation, into natural and artificial reservoirs. (b) From the method of their functioning, into storage and detention reservoirs. The subdivisions under (a) may merge to some extent, as where natural lakes are dammed and thus become in part artificial. Under (b) all natural reservoirs in their unmodified state are detention reser-

voirs; (See Paragraph 44), that is, their action is purely automatic. Most artificial reservoirs are built for storage purposes and have outlets under control, but some few have been built purely as detention reservoirs with outlets permanently open. Occasionally there is a combination of the two purposes.

(37) Natural Reservoirs. Natural reservoirs are of universal occurrence and no important stream is free of their influence. The more important are:

(a) The ground—greatest of natural reservoirs except the sea. Permeable soils, particularly great gravel deposits, make almost perfect regulators.

(b) Next in importance are natural lakes and ponds. These are effective regulators, and in a few cases, like the system of the Great Lakes, produce well-nigh complete control.

(c) Overflow basins and swamps into which flood waters pour themselves. The St. Francis and Yazoo basins on the Mississippi and the several basins of the Sacramento are examples. The Sacramento basins are estimated to have stored 175 billion cf in the flood of 1907, while the capacity of the Mississippi basins above Red River probably exceeds 5000 billion cf.

(d) Snow and ice are natural reservoirs of prodigious magnitude, and differ materially from others in that there is no outflow unless the temperature is above a certain point. Great drifts prolong flow after melting begins and glaciers are a perennial source of outflow.

(e) Many set great store upon the reservoir function of forest humus.

(f) Stream channels are a most important flood regulator. For example, to fill the Ohio from Pittsburg to its mouth from low to highest stage requires 1000 billion cf;* and similarly to fill the Mississippi between levees from Cairo to the Gulf requires 2000 billion cf.†

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*Estimate based upon 31 measural cross-sections about 30 miles apart, adding 50 per cent for overflow of bottoms, backing up of tributaries, etc.

† The estimate for the Mississippi is from p. 58, Van Ornum's "The Regulation of Rivers".

(38) Under (b) of the preceding paragraph natural reservoir control is less complete than might be expected because the outlets have become proportioned to the reduced outflow, and have less capacity than if the regulation were absent. This condition is very pronounced on the upper Mississippi below the lakes near its source.

(39) Since the flood problem, as herein discussed, is man's problem, and since Nature's reservoirs are always in operation anyway, they will not be considered in this paper except when useful for illustration, or when they are converted into artificial reservoirs.

(40) Storage Reservoirs. Storage reservoirs, as the term is here used, are artificial reservoirs built to store water for some definite use later, as power, domestic use, navigation, irrigation, etc. Flood prevention is a secondary purpose usually, though not always. Such reservoirs are provided with sluices under control.

(41) Conflict of Purpose. This ordinary purpose of storage reservoirs is in direct conflict with the requirements for flood prevention. If storms could be foreseen, both in date and intensity, this conflict could be compromised. But as they cannot be foreseen, and as experience shows that precipitation of one season may be several times greater or less than that of another, it becomes important, for storage purposes, to fill the reservoirs as soon as possible so as to be sure of a supply; while, for flood control, it is important to reserve ample space in them until the season of storms is safely past. The two purposes are thus essentially antagonistic. They can be harmonized wholly or partially in two ways—first, by building the reservoir so large that it will store in safety the whole yield of a season; second, by determining an adjustment between flood prevention and industrial use, taking some chances with each.

(42) There are many sites, particularly those containing natural lakes, where storage in excess of the annual runoff can readily be secured. Such reservoirs serve equally well both flood prevention and storage purposes. They may often be made to do more, and may even up those cyclic fluctuations

which extend over a series of years. The upper Mississippi reservoir system is an example.

(43) As to compromise of purpose, there will always be a peril involved in the selfishness of interests dependent upon stored water. Long periods of low water dull the public sense of danger and it becomes a contest between an aggressive and insistent private appeal and a lethargic public sense of duty. The chances are strong that the private appeal will prevail; and that the flood reserve space will be encroached on until a catastrophic storm comes and finds the provision made for it pre-empted. This is undoubtedly a real danger.

(44) Detention Reservoirs. The conflict of purpose referred to above, furnishes the *raison d'être* for the detention reservoir. Storage considerations are eliminated and flood prevention is the only purpose. The sluices are left wide open at all times and are so proportioned that, when the reservoir is full, the outflow will not exceed the capacity of the channel below. The entire ordinary discharge passes freely. After the crisis of the flood is passed, the detained water runs out rapidly, and the basin is soon empty. As floods usually occur before the crop season, the basins are generally available for cultivation. The soil is enriched by the deposits from floods. The operation is entirely automatic, free from private interference, deterioration or failure of gates, and bungling of results through careless handling. The first example of this kind was the Pinay Dam on the Loire in France; built in 1711. It was not a complete dam at all, but an artificial narrowing of a gorge to the required limits of flow capacity. A few reservoirs of this class have been built in Germany. The two most notable projects yet proposed are those for controlling floods at Pittsburg, Penn., and at Dayton, Ohio. They involve combinations of reservoirs, (seventeen at Pittsburg and seven at Dayton). The Pittsburg system consists entirely of storage reservoirs; that at Dayton is automatic only. The working out of the relation between the various tributary peaks and the main flood peak at the point or points to be protected is a complicated problem. The first comprehensive effort to subject this problem to a thorough analysis is believed to be that of the Pittsburg Flood Commission in 1911. By far the most exhaustive

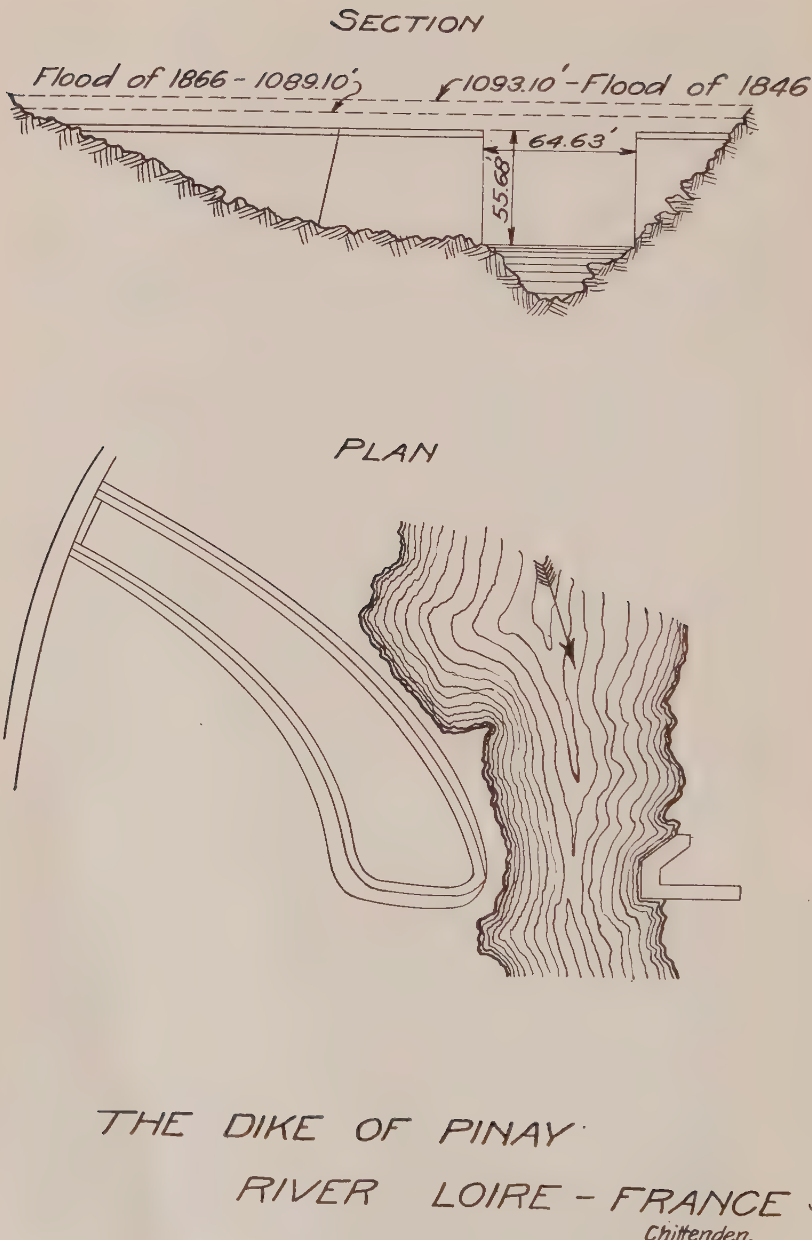

Fig. I. Digue de Pinay. The Original Detention Reservoir.

and scientific study, however, is that by the present Dayton Flood Commission. These examples will be considered more fully further on. In general, the chief distinctions between storage and detention reservoirs are these: The storage reservoir serves in greater or less degree all the purposes of reservoirs, but flood prevention is served less as other purposes are served more; the detention reservoir serves only the single purpose of flood prevention. The space occupied by storage reservoirs is permanently lost to other use; that occupied by detention reservoirs is available for agricultural use.

(45) Overflow Basins. The overflow basins referred to in Paragraph 37 (c) are natural detention reservoirs of enormous capacity. Discharge from them begins almost simultaneously with the process of filling and reaches its maximum when outflow balances inflow. When a flood is followed by another at a short interval, the basins, having been filled by the first flood, produce much less moderating effect on the later flood and may even aggravate it. But on the whole, the storage effect of these great reservoirs on the Mississippi is amply proven by the progressive increase of flood height coincident with cutting them off by levees.

(46) Peculiarities of Control. While a storage reservoir is filling, if the gates are kept closed, the flood control immediately below is more complete, until the spillway is reached, than with a detention reservoir from which there is always an outflow. Even after the spillway is reached there remains a degree of control. In order that overflow may take place the surface of the reservoir must be raised by an amount equal to the depth of overflow, and the quantity thus stored is abstracted from the runoff. If the width of the spillway be relatively small, and if the reservoir area be relatively large, the regulative effect above spillway level may be considerable. This is the actual working of all natural lakes, and the maximum outflow for any flood crest can never be as great as the maximum inflow. Such a reservoir however, if closed by an artificial dam in the outlet, may actually operate to increase the flood flow over natural conditions. In a state of nature such a reservoir, as above pointed out, always exercises a certain regulative effect. But if, in converting the natural into an artificial reser-

voir, a flowage line has been adopted which cannot for any reason be exceeded, and if it should happen that a flood-producing storm should find the reservoir filled to its limit, it would then become necessary to manipulate the sluices and the spillway gates so as to release the water as fast as it comes in. This would increase the outflow over what it could possibly be in state of nature. This contingency was practically reached on the upper Mississippi in the flood of 1905.

(47) Diminishing Influence Downstream. The influence of reservoir storage in flood prevention is greatest immediately below the dam and diminishes rapidly downstream. This is due to the storage absorbed in the channel, to the flattening out of a flood wave as it progresses downstream, but principally to the fact that channel capacity increases as tributary watershed below becomes effective, and a given accession from above has relatively a constantly diminishing effect on gauge light. In addition to these considerations is the very important one discussed in the next paragraph.

(48) Tributary Combination. Flood heights on lower courses of great rivers are results of fortuitous combination of tributary accessions. A reservoir on a small tributary, even if it holds back all its flow at a flood crisis on that stream, may have some useful effect far below, or none at all, depending upon whether its flow, if not held back, would have arrived at a given point simultaneously with the flood peak there, or considerably before or after. With detention reservoirs, the whole flood flow is promptly released after the local crisis. Whether the short delay would accomplish some reduction far below, or none, or even the reverse, would depend upon the coincidence of the delayed arrival with the local crest from tributary combination. The chances seem as favorable for one contingency as the other. Thus, in the case of the proposed Miami River detention system (Paragraph 126), a very high discharge for three or four days will be spread over, say, two weeks. It would probably make little difference in the effect on the flood at Cairo whether this quantity were spilled into the Ohio (470 mi above) in one or two weeks' time. The local effect at Dayton would be very great. The effect on the lower Mississippi would be slight, and as liable to be unfavorable as favorable.

The same argument applies to releases from storage reservoirs at any time during the period of probable floods.

(49) Ineffectiveness of System. The foregoing considerations disclose the fatal defect of the reservoir theory as applied to the lower courses of great rivers. To have held back enough water to have lowered the 1912 Mississippi flood at Cairo, 1, 2, 3 and 4 ft would have required reductions of discharge by the following quantities at that point.*

For a lowering of 1 ft	60 billion cf
" " " " 2 "	200 " "
" " " " 3 "	350 " "
" " " " 4 "	500 " "

As just intimated, and as stated by the President of the Mississippi River Commission in a recent address, "Cairo is the logical location for a reservoir to regulate the discharge of the lower Mississippi". But no available site of sufficient magnitude exists there. James A. Seddon, M. Am. Soc. C. E., proposed several years ago to convert the St. Francis Basin into a series of reservoirs by cross levees running east and west. He figured out that such a system would hold floods within river banks while the water stored would maintain low water navigable depths below Helena. The manifest complexities of the project, its enormous cost and its interference with reclamation caused it to be received with disfavor by river engineers. It might be practicable to utilize as a reservoir the territory extending west from the river about 15 mi to high ground and from about 20 mi above Cairo to about 45 below (channel distances). An average depth of 10 ft over this area would reduce by more than one foot the crest of a flood like that of 1912. But apart from the grave complications involved in the project, it is very doubtful if the gain would at all justify the cost.†

(50) Concentration of storage where it would be the most effective being thus wholly impracticable, it would be necessary

* These estimates are as close approximations to average results as it seems practicable to obtain. The variations in discharge for the same stage are so extreme near flood crest that estimates may easily vary by 25 per cent, dependent upon assumptions, any one of which seems warranted by the record of discharge measurements.

† In this connection turn back to paragraph 37 (f) and note what prodigious reservoirs Nature has already provided for this stream exactly where most needed.

to have many reservoirs scattered over the flood-producing portions of the watershed. Considering that floods at this point never come simultaneously from the various tributaries, but sometimes mainly from one and sometimes mainly from another; that water released from reservoirs (either detention or storage) during the flood period is liable to augment combinations below; that only the water withheld from the flood crest is really effective; and that, due to the rapid diminution of local effects with progress downstream, a given amount of storage is less effective the farther it is from the point of protection, it would seem to follow that an efficient reservoir system must embrace all the territory which is really effective in producing floods, and that it must be large enough on every portion of such territory to insure the necessary control if a flood should originate in that portion. The system must therefore overspread practically all the Ohio watershed, the upper Mississippi, and the Missouri as far west as the semi-arid belt. Its complete development, to be a positive insurance against possible combination, would have to be several times—one can only conjecture how many—as great as the volume to be withheld at the point of protection. It is the necessity of facing these prodigious quantities that shows how visionary is the idea of reservoir control of the lower Mississippi floods.*

(51) Incidental Drawbacks. (a) A storage reservoir is itself a condition of flood—permanent overflow of a fixed area. As a flood prevention proposition it is of doubtful economic merit. If the land thus withdrawn and the lands protected are of equal productive value, the account, considering the time of submergence of each, would probably stand against the reservoir. Detention reservoirs are not subject to this disadvantage.

(b) Dam failures are not infrequent and have produced some appalling disasters. There is much popular apprehension concerning them. Depreciation of property values below dams possibly offsets the enhancement of value from flood prevention. No dam should be built unless natural conditions and technical plans are such as to give absolute warrant of safety.

(c) In storage reservoirs, the margin uncovered by fluc-

* For a clear analysis of this subject see Van Ornum's "The Regulation of Rivers", p. 67.

tuation of level is unsightly and sometimes unsanitary, as when it impregnates domestic supply with filth and decaying vegetation which have accumulated during recession of the water.

(d) Liability to destruction through filling up with sediment is often urged against the use of reservoirs. Examples abound in Nature of lakes and ponds so filled up. But these processes are generally very slow, and except in a few situations where streams carry abnormal loads of sediment, this consideration has little weight in determining the practicability of a reservoir project.

(52) Ground Reservoirs. The storage capacity of permeable soils has been referred to. It often happens that such underground reservoirs are separated from the surface by layers or strata more or less impermeable, or that the permeable strata outcrop in very limited areas. In such cases the quick action of floods permits no time for percolation through the less pervious covering and the ground storage is lost, so far as flood control is concerned. It has been proposed in some instances to provide artificial connections between the surface and the ground storage. This scheme was put forward with persistence in the investigations following the Paris flood of 1910. It was proposed to sink a great number of *puits absorbants* (absorbant wells) into the permeable zone which underlies portions of the Seine watershed. The scheme was not adopted however.

(53) In many situations in the western sections of the United States, particularly on the Pacific Coast, vast gravel deposits lie close to the surface and absorb water with great rapidity. These are much used as sources of supply, and in recent years some effort has been made to keep them replenished by facilitating the absorption of flood waters. The Livermore gravels, across the Bay from San Francisco and a part of that city's water supply, are an example. See also the description of the Los Angeles flood problem, Paragraph 141. The great difficulty of the application of any method of ground storage in time of flood is that arising from the high volume and short duration of flow at flood peak. The water comes too fast to be absorbed, and flows on past the area of absorption. On a limited scale the system promises good results, but its real value is in storage for low water use.

VIII. FLOOD PROTECTION.

(54) Channel Capacity Increase. Measures of flood protection contemplate no reduction in the flood volume itself, but are confined to taking care of the flood as it comes. This is accomplished by some form of increase of channel capacity and embraces the following measures:

(a) Increase of slope, generally by shortening the channel by means of cutoffs.

(b) Provision of secondary channels to carry a portion of the flood flow. This embraces bi-passes and outlets, more or less interchangeable terms, and includes also diversions around particular points.

(c) Increase of channel section by enlargement downward or sidewise. This involves artificial excavation or natural scour induced by artificial aid.

(d) Increase of channel section by enlargement upward. This is the levee system, by far the most universally used of all systems of flood protection.

(55) Cutoffs. Increase of slope increases velocity and diminishes gauge height for a given discharge. The only practicable method of increasing slope is that of shortening channels by cutting off bends. Sinuosity of channel is a characteristic of all streams and in some instances is developed to an extraordinary degree. In large rivers, flowing in beds of their own alluvium, the opposite processes of developing bends and of cutting them off are in active operation; but on most streams the process of change has largely ceased, the bends are comparatively permanent, and the existence of excessive sinuosity is, at first thought, inexplicable. The condition undoubtedly dates from a time when the land through which such streams are flowing was in process of emerging from lakes or tidal estuaries. The current over the soft and unstable bottom was easily diverted here and there by obstacles of any sort. Windings of the most extreme character began in this way, and as the bottoms rose by deposition, the channels grew deeper, until with complete emergence and occupation by vegetation, as well as slow compacting under accumulating weight, the banks became hard and firm, and the phenomenon of winding channels

in a stable soil has resulted.* Almost invariably the slope is very slight and generally the channel capacity wholly deficient for the ordinary flood flow. Neither in this class of streams nor in those in which channel changes are in active progress is the operation in its origin other than accidental. To say that the process is "necessary", that bends "must" occur, as engineers often express it, is no more justifiable than to say that ruts in a road must occur where they do, or must even occur at all. Left to themselves these things do occur, but with guidance or restraint at the right time they might easily be prevented, or be made to occur in different places or directions.

(56) The distinction between sinuosities which are now permanent and those which are in process of development is important, for it furnishes the criterion of the practicability of the cutoff method. In the first class, cutoffs are extensively used both for flood relief and for drainage as well as the avoidance of bridge crossings and the removal of sharp curves in which ice and drift accumulate. They are a very important resource to the engineer. The most extensive system ever yet executed is that of the river Theiss in Hungary where 112 cutoffs reduced the original length of channel from 758 miles to 477 miles.† On the other class of streams the utility of cutoffs is doubtful and in some instances they are considered highly injurious. This is the case on the lower Mississippi where official policy is absolutely against making cutoffs or permitting

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* The most striking example in existence is that of the great plain of Hungary, which was a fresh water lake (*mare dulce Pannonicum*) until about the Quaternary epoch, when the Danube broke through the Carpathian barrier at the Iron Gate. All the streams in this old lake bed have excessive sinuosity. So also in our own country Red River of the North has wrought its course in the bed of the ancient Lake Agassiz.

† This is only a part of the work of straightening the streams of the Hungarian plain. It embraces eleven rivers, among them the Danube, the Drave, the Save and the Theiss. The total number of cutoffs so far made is 717 and the total channel shortening is more than a thousand miles. The Danube is shortened by 17 cutoffs about 76 miles in a section where the banks are very unstable and bank erosion constantly going on. These cutoffs have effected a material lowering of flood heights and there is no suggestion of a contrary effect in the very complete review of the subject from which these data are taken. Authority, M. Eugene Kvassay, Chief of the Hungarian Bureau having in charge Public Waterways.

them to occur naturally. The reason usually assigned is the far-reaching disturbance which results to the regimen of the river, but it is probable that interference with conditions growing out of occupancy of the banks has quite as much to do with the matter.

(57) An Objection of Doubtful Validity. It is persistently urged against cutoffs, as a measure of flood protection, that they tend, in the words of De Mas, to "bring more water in a given time to the lower portion of the valley" than would be the case without them. A close analysis of this objection will probably convince anyone that it is largely unfounded. Except for some diminution in channel storage (which at high flood would be slight), and some diminution in the flattening out of the flood wave, it is impossible that cutoffs can increase the volume of water brought to the lower part of the valley. The water gets there sooner, but not in greater volume, and it is volume, other conditions being the same, that determines gauge height. Attributing the destruction of the city of Szegedin, Hungary, in the flood of 1879 to the cutoffs on the Theiss appears to be entirely unwarranted.

(58) A Common Mistake. The mistake generally made in resorting to cutoffs is in not properly estimating and providing beforehand for the temporary disturbing effects likely to follow. Misfortune which might easily be avoided at small expense often results from neglect of this precaution. Nature's methods cannot be departed from with impunity, and when such departures become necessary, thorough consideration of the consequences should be given and the proper steps be taken in anticipation.

(59) Bi-passes. A bi-pass, strictly speaking, is an auxiliary channel which diverts a portion of the current for a greater or less distance. The principle is found in actual operation on many streams in a state of nature. The great overflow basins of the Mississippi were not only immense reservoirs but auxiliary channels of flow. It is urged by advocates of the system that this example of Nature should be followed, but that the width of the auxiliary channels be greatly curtailed by levees, thus cutting out a part of the reservoir function and reclaiming a portion of the basins. Such a bi-

pass on the Mississippi would start from Cairo on the west side, continue down the St. Francis Basin, cross to the Yazoo Basin, cross again to the west side at the foot of the Yazoo and continue thence to the Gulf absorbing Red River on its way. It has also been proposed to retain the bi-pass all the way on the west side. On the Sacramento two courses have been proposed, one lying entirely on the west side, and the other on the east side above the mouth of the Feather River and on the west side below. The Sacramento bi-pass would rejoin the main stream on its lower course, while the Mississippi bi-pass would form an independent channel to the Gulf. The Mississippi plan has been rejected because it is practicable to control extreme floods between levees, and thus permit a much larger area of reclamation. The bi-pass system has been adopted on the Sacramento, because of the impossibility of confining floods within levees. Bi-passes are sometimes proposed in order to relieve important points. The Paris Flood Commission of 1910 proposed a diversion of the Marne (which joins the Seine just above Paris) north of the city to a junction with the main river below. This was estimated to lower a flood like that of 1910 in Paris between 4 and 5 feet. The plan has since been deferred in favor of that of channel enlargement.

(60) Outlets. The outlet system applies particularly to deltaic rivers, and, like the bi-pass system, is following the example of Nature. On the lower Mississippi there were originally many of these openings below the mouth of the Red River through which flood waters found relief into the lowlands and swamps and were gathered up in bayous and conducted to the sea. Even above Red River there were many such openings leading into the basins, but, as the water from these generally returned to the river, they were more in the class of natural bi-passes. The development of the levee system on the Mississippi has closed all these outlets except one, which has been considerably enlarged over its natural capacity. That is the Atchafalya which takes out at the mouth of the Red River, absorbing the whole of that stream and a large additional flow from the Mississippi in time of flood.

(61) Objections to Outlets. It is a general rule that the more completely a stream can be confined to a single channel,

the better it is for all interests affected. Division of the force of the current by numerous channels diminishes its power of self-maintenance. On the lower Mississippi such outlets were obstacles to reclamation and therefore objectionable. But the progressive closing in of the river has increased flood heights, and at New Orleans, where wharves and grades have become established, has created a situation of some danger and has made it desirable to relieve some of the discharge. There seems to be no reason, so far as the river is concerned, why this should not be done. The argument that such an outlet would have the same effect upon the regimen as a crevasse is not well founded. A crevasse is a sudden, violent change of great magnitude and depth; an overflow weir a mile or two long comes into operation gradually, carrying off the top waters, and should have no serious disturbing effect. The chief objection to the system, where it is being considered near New Orleans, relates to the outlet itself and its effects upon railroads, drainage, sewerage, the navigation of lakes Borgne and Ponchartrain, and to the possible destruction of the outlet channel by deposition of sediment.

(62) Channel Enlargement Downward and Sidewise. The larger the area of cross-section for a given form and slope, the greater will be the discharge. Enlargement of cross-section is therefore a measure of flood relief. If the gauge height is to be held below a fixed level, channel enlargement must be downward or sidewise. This involves mechanical excavation, with such aid as can be derived from current scour. As a rule this method is inapplicable on larger streams because of its cost. Besides the obstacle of cost there is doubt as to permanence. Streams tend to restore depressions in the original slope line and unless excavation be carried far enough to maintain the original or a steeper slope throughout, and avoid an intermediate depression, the chances are that it will fill up. No amount of excavation on the Missouri, for example, would have the slightest permanence. In two notable instances this method has been proposed. The most recent proposition for flood control of the Seine contemplates excavation from Port à L'Anglais just above Paris to Rouen near the mouth. The 1904 Flood Commission on the Sacramento recommended extensive

excavation coupled with a pronounced elevation of levees. It was expected that the increased velocity would induce heavy scour and thus materially assist mechanical excavation.

(63) In congested situations, as in cities, important results can be obtained by widening and deepening channels, clearing them of obstacles, and the bed of all hard materials to a considerable depth, supplementing this work with revettment of banks. Then, if the bed does fill up somewhat with soft alluvium, it will yield to scour under high velocity and floods will thus in a measure excavate their own channels in the hour of need. A case was observed on the Kaw River in Kansas City in the flood of 1903 where the bottom scoured out 30 feet, and the plan of improvement on that stream assumes a scour of 15 feet under the force of a high flood. This presupposes a thorough dredging of the bed of all hard material down to the assumed depth of scour.

(64) Channel Enlargement Upward. Levees. Lateral enlargement is least effective in increasing capacity and is most costly, for it requires both excavation and acquisition of site. Moreover, valuable space for useful occupancy is absorbed. Vertical enlargement increases capacity more rapidly for the same increase in cross-section, avoids land damages and does not restrict occupancy. If the enlargement be downward, the cost of excavation may be a serious drawback. That is why vertical enlargement upward is the most practical of all methods. The air costs nothing, it does not have to be excavated, and the only measures necessary are relatively inexpensive embankments on the sides to raise the surface to the necessary height. The simplicity, effectiveness and economy of this method have caused its universal adoption, dating from remotest antiquity. There are no unverified theories about it. The unprofessional mind can grasp its operation at once, and the work, as a rule, is certain in effect and the cost determinable beforehand within close limits.

(65) Increasing Flood Height. Two characteristics of levee systems may here be noted—one well established as the result of definite causes, the other apparently unfounded and more in the nature of a superstition. Levees do have the effect of increasing flood heights. By cutting off overbank flowage

space, which is really a part of Nature's flood channel, an increased burden is thrown upon the restricted channel between levees. This arises from the elimination of both the reservoir and bi-pass functions of the bottom lands. Levees thus increase their own height and the full extent of this increase seems never to be anticipated, or at least admitted, by those responsible for the development of great levee systems. The levees of the Po, the Theiss and the Mississippi have been progressively raised as earlier work has proven inadequate. The Mississippi River Commission, fully recognizing this tendency, but not yet venturing to predict its ultimate development, has followed the practice of establishing "provisional" grade lines, the latest being that of 1914 based upon the flood heights of 1912 and 1913.

(66) Elevation of Bed of Channel. Possibly as an inference from the tendency noted in the previous paragraph, there seems to be a well-nigh universal belief that levees cause a rising of the bed of the channel and in that way enhance the evil of floods. It is difficult to assign a reason for such a conclusion. Theory would lead in the opposite direction. Surveys on the Mississippi do not show any evidence of such a tendency, nor much to the contrary, though they indicate that there is some. The claim once put forward by a French engineer, De Prony, that the bed of the Po was rising was stoutly denied by the Italian engineer, Lombardini; but correspondence of the author with an Italian engineer, Luigi Luiggi, indicates that there is a rising of the bed to some extent. This, however, is not a fault of the levees but is due to increasing erosion in the Apennines which produce excessive deposits in the upper valley, and the increasing progression of the delta into the sea by which an increasing height of channel becomes necessary in order to maintain slope. As to the general regimen of a river like the Mississippi, the effect of levees must be, in the long run, beneficial, for, by diminishing the vast irregularities due to unrestrained overflow, they must naturally tend to the development of a deeper and more uniform section throughout the channel.

(67) Types of Levees. The levee section, the material used, and the method of construction vary with each particular

case. Conditioned upon the space available, the height of water to be sustained, the value of the property to be protected and of interests to be served, and numerous other circumstances, the type and character of the work will range all the way from the frail earthern dike which holds back a few inches of overflow from a farmer's land to mighty masonry walls like those which enclose the Tiber in the city of Rome. The standard section for a Mississippi levee 20 ft high is as follows: Top width 8 ft; river slope 1 on 3; land slope 1 on 3 to a banquette 8 ft below top; banquette 40 ft wide with top slope of 1 on 20; slope from banquette to ground 1 on 4. A trench called a "muck ditch" is placed underneath and a little in front of the top of the levee. It is 8 ft deep and 8 ft wide on the bottom and is filled with the best material available. Levee slopes are grassed over as firmly as possible. Material of construction is taken from the river side. Considerations of economy compel use of material immediately at hand which is often of inferior quality. Some study has been given to the proposition to provide a sheet pile cutoff underneath, to be continued to the crest by a concrete cover of the river face of the levee. This would prevent saturation of the levee, seepage through the foundation, erosion from wave wash, and would thus eliminate the chief dangers to the integrity of the system. The much greater cost of this quality of work will probably restrict its use to situations of particular difficulty in making the ordinary levee hold.

(68) Maintenance of Levees. The maintenance of levees is a problem often exceeding in difficulty that of construction. As already pointed out, economical limitations prevent really secure work, such as would be insisted upon in building earthern dams. Levees are therefore peculiarly liable to collapse under heavy strain. The chief dangers while the flood is below the levee top are saturation and sloughing of the land slope, filtration through the levee section, filtration through the foundations, and erosion from wave wash. Usually, by vigorous measures, these dangers can be controlled. Overtopping of the levee, if it develops into an actual overflow, is a certain cause of destruction. On the lower Mississippi, flood fighting has developed into a great system and the feats accomplished in

holding levees are truly marvelous. Not less so have been some of the successful attempts to close crevasses before floods have fully subsided. A very serious danger to levees, though not more pressing at high floods than at other stages, is that from undermining through the erosion of the banks on which they stand.

(69) Drawbacks of Levee System. Simple and economical as the levee system is, it is not without its drawbacks, some of them of a serious character.

(a) In cities the obstacle of grade elevations, where streets are well established, may be, and generally is, so great as to prohibit raising levees to the necessary height to secure full protection.

(b) Where tributaries come into the main stream, the levee line cannot be closed. If the adjacent country is not to be flooded by back water, the levees must be drawn back up the course of the tributary far enough to protect the bottom from backwater. But this cuts off drainage in the pockets near the junctions, and local runoff must be permitted to accumulate or be removed by pumping.

(c) On most rivers where levees are used there are stretches along bluff shores where the bottoms are too narrow to justify the cost of levee protection. The raising of flood heights due to levee construction above and below and on the shore opposite is a direct detriment to such lands.

(d) Aside from the above drawbacks, and others of less importance, levees are an ideal system of flood control. They have been used the world over in all ages and in an infinite variety of situations. The value of property made possible of development by them is inestimable. That they will continue to be the chief measure of flood relief admits of no doubt.

IX. COMPLEXITIES OF THE PROBLEM—PHYSICAL AND FINANCIAL.

(70) Physical Complexities. The foregoing discussion shows how extremely complicated the flood problem is. No rule is applicable to all situations. Each case must be diagnosed and treated by itself. In most, a combination of two or more methods is advantageous, especial reliance being placed upon

some one. "Levees only" for the Mississippi and the Po; levees and cutoffs for the Theiss; levees and bi-passes for the Sacramento; levees and channel enlargement for Kansas City; reservoirs (storage mainly) and levees (vertical wall) for Pittsburg; detention reservoirs, channel work and levees for Dayton and the Miami; cutoffs and levees for Columbus; ground storage, channel work, reservoirs and levees for Los Angeles; levees and bank protection for the Colorado, etc., etc. It is noteworthy that in some of the greatest systems levees are practically the only method, while they are a more or less important auxiliary in all. The flood engineer must be bound to no system, but, with judicious insight, determine the treatment which best suits the particular case.

(71) Financial Complexities. Money being a *sin qua non* in the solution of any flood problem, the method of procuring the necessary funds is quite as important as the method of solving the physical problem. A question of broad policy may be considered first. Is it wise, as a rule, to provide for those extreme visitations which occur only once in a generation or so? Would it not be better to stop with provision for high floods, accepting the very rare deluges, with such emergency measures as might be practicable at the time, and then foot the bill of damages? This is the universal practice of the railroads, which are perhaps the greatest sufferers from floods. They have learned from experience that such is the more economical course, and it would be easy to demonstrate that, as a mere question of profit and loss, the same would be true of many of the great flood problems of the country. There are, however, other considerations than profit and loss which in some cases determine the question.

(72) In providing funds for flood control a great difficulty is always that of quick recovery of the public mind from the shock of disaster. In very few cases are great floods of frequent recurrence. Five, ten and fifteen years are common intervals for ordinary floods. The public interest and willingness to contribute wane rapidly with the passage of time. As the havoc of the flood disappears—and it disappears more rapidly than that of any other visitation—as nature clothes devastated fields with fresh life and as new structures arise on

the ruins of the old, those who have suffered from the flood are forced by necessity to consider those direct measures which shall most quickly rehabilitate their damaged fortunes. Their very losses make them loth to part with more money except for direct recoupement. They review the past, note how seldom such calamities occur, and reason that in their lifetime no similar one will again occur. Why, then, impoverish themselves further? There is a great deal to this argument and only the frequent recurrence of disaster can overcome it effectually.

(73) Raising of Funds. Individual effort does a great deal where the situation is such that a problem can be dealt with piecemeal. But in the general case cooperation in some form is a necessity. This is accomplished by public agencies, either already existing or created for the purpose. Under the first head fall towns, counties, states and the general government. Under the second is some form of assessment district. These are variously known as drainage districts, levee districts, etc. The first class of agencies contribute funds on the broad theory of the general welfare; the second on the theory of specific benefits. In many, perhaps most, instances, a combination of methods is used. This is particularly true in Europe where the state usually cooperates with local agencies. Theoretically this combination of effort seems the most equitable method. It is rare that the local community is sole beneficiary. Transportation is interrupted, and in the modern interdependence of all interests, no community can suffer without the whole body being affected. Therefore it is well that the state (in our country the individual states or the General Government) assist local agencies in carrying out the more important projects. One of the most serious difficulties in this country is that, when a community has become familiar with government contributions to river and harbor works without local aid, it loses the spirit of self-help and gets into the habit of looking to the Government to bear the whole expense—even in other fields, such as that of flood control. Nevertheless the general principle of cooperation is coming to be more and more recognized and will eventually work itself out into an established system.

(74) Conflicting Jurisdictions. One of the most serious of practical difficulties in the work of cooperation arises from the fact that the physical problem may concern two or more independent political or civil jurisdictions. When these are within a single state—as towns, cities, or counties thereof—State legislation can supply the machinery for cooperation. But when the contiguous jurisdictions are States—which in this country are as independent of one another in all matters of this kind as are independent states in Europe—there is no authority that can compel cooperation. It must be wholly voluntary, and the difficulties of agreement are generally so great as to make thorough-going cooperation impracticable. The case of the Kansas City flood problem, to be referred to further on, is a striking example. (See also Paragraphs 136, 145 and 158.)

(75) Constitutional Limitations. The right of the government to appropriate money exclusively for flood control, even on navigable streams, is held not to exist under the Constitution, and this involves some policies of indirection which are scarcely creditable to a great nation. The government regularly appropriates money for purposes which, it is understood, are not permitted under the Constitution. Levees are being built on the lower Mississippi, reservoirs on the upper Mississippi, levees and bi-passes on the Sacramento, reservoirs throughout the arid regions, and national forests are being created in the Appalachians. The ostensible purpose for which this money is appropriated, except in one case, is aid to navigation; yet it is well known that levees on the Mississippi do not help navigation materially, and that the same is true on the Sacramento; reservoirs on the upper Mississippi do aid navigation a little but flood control and industrial use are the real ends served; irrigation, by abstracting water from the streams, injures navigation more than it helps, while it stands today unproven that forests have any beneficial influence worth considering upon navigation. All these measures have been provided for under assumptions which are not true. All are worthy purposes which can be accomplished only through government aid, and it seems a pity that they must stand on a false foundation. This would not matter so much, if it were only a question of the examples cited, for the policy of aid having been

once inaugurated, even on fallacious premises, will doubtless continue. But the prohibition which is evaded in these particular examples stands in full force as to others and thus prevents comprehensive action. There is no reason why flood protection by federal agencies should be restricted to navigable streams, and no reason why forests should not be developed for timber production alone. If the power does not exist under the Constitution, then the Constitution should be amended.

Part II.

SOME NOTABLE FLOOD PROBLEMS OF THE UNITED STATES.

(76) Ubiquity of Problem. The flood problem is ubiquitous in its application. In almost every community exist conditions requiring applications of the principles above set forth. There are presented below the distinguishing features of a few of the more important examples in the United States, but the list might be extended indefinitely.

I. THE MISSISSIPPI PROBLEM.

(77) General Statement. The greatest flood problem in the world today undergoing active development is that of protecting from overflow the bottom lands of the Mississippi River from the mouth of the Ohio to the Gulf. Following are the essential data involved:

(78) Distances.

Length of channel from Cairo to the head of the Passes	1060 mi
Length with sinuosities eliminated, about	620 "
Air line distance to outlet of Atchafalaya River, about	500 "

(79) Watershed Areas.

Missouri River	527,150 sqm
Mississippi above Missouri	165,900 "
Ohio River	201,700 "
Arkansas River, including White	186,300 "
Red River	90,000 "
Local (including St. Francis, Yazoo, etc.)	69,000 "
Total	1,240,050 "

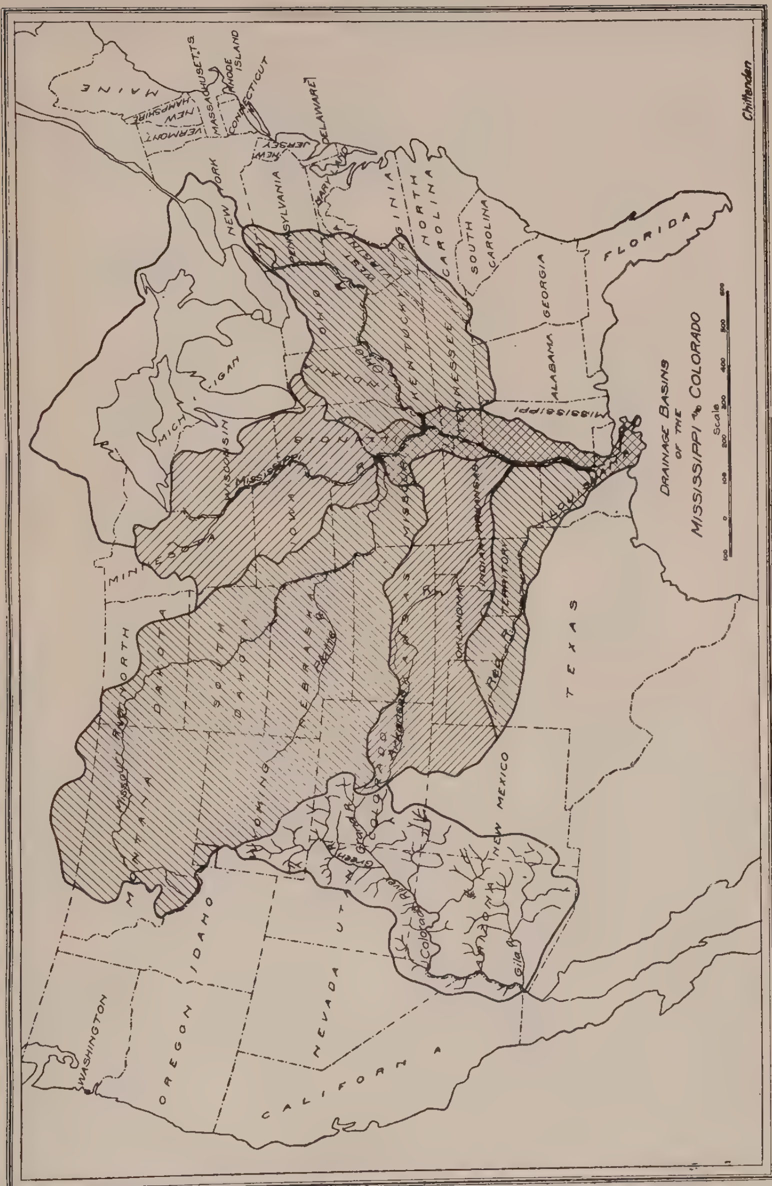

Fig. II. Watersheds of the Mississippi and Colorado Rivers.

Of these areas about 425,000 sqm on the Missouri, 125,000 sqm on the Arkansas and 30,000 sqm on the Red lie in the arid or semi-arid belt and play a wholly unimportant part in producing the floods of the lower Mississippi.

(80) Rainfall. The mean and maximum annual rainfalls at selected points within the flood-producing zone are shown in the following list:

Locality	Mean Annual	Maximum Annual
Omaha	29.7 in	48.9 in
Kansas City	37.0 "	50.3 "
St. Paul	28.7 "	49.7 "
Davenport	32.3 "	46.8 "
St. Louis	40.0 "	68.8 "
Pittsburg	36.3 "	50.6 "
Cincinnati	38.3 "	54.7 "
Indianapolis	41.0 "	57.7 "
Chattanooga	50.7 "	68.0 "
Nashville	48.5 "	67.2 "
Cairo	41.7 "	61.6 "
Memphis	50.3 "	73.5 "
Little Rock	49.1 "	75.5 "

(81) Storms. The Ohio is the great determining factor in the floods of the lower Mississippi, though the immediate effect from local territory within fifty miles of the river from St. Louis to Vicksburg must be relatively much larger. Storms affecting the lower Mississippi and Ohio basins originate in the Gulf and move from the Texas Coast northeast, the axis of the storm zone being almost parallel to the Ohio River, sometimes north and sometimes south of that stream. The time consumed in thus crossing the watershed is two to three days. This order of progress is undoubtedly advantageous so far as floods are concerned, as compared with what it would be if in the opposite direction. Storms on the lower Missouri and upper Mississippi watersheds are not closely coordinated with each other or with those on the Ohio, and flood waves from these sections rarely occur simultaneously with each other and still more rarely with those from the Ohio. The "June rise" from the Rocky Mountains is quite outside the flood period on the lower

river and is negligible as a flood factor. Probably the great bulk of all lower Mississippi floods originates within 400 mi of Cairo.

(82) Runoff. The watershed presents every conceivable variety of "permeable" and "impermeable" soils, is subject to snow and frost in the northern sections, and the flood-producing portion is about one-third wooded. The floods usually come in the first four months of the year. The maximum discharges on the main stream and the tributaries and the corresponding rates of runoff are shown in the following table:

Name of Stream	Discharge	Rate of Runoff
Mississippi at Cairo	2,015,000 cfs	1.6 cfsm
Missouri	900,000 "	1.7 "
Mississippi above mouth of Missouri	450,000 "	2.6 "
Ohio	1,400,000 "	7.0 "
Arkansas*	450,000 "	2.4 "
Red	350,000 "	3.9 "

The local runoff from the 69,000 sqm must average higher than any of the above rates but it has never been determined. The low rates on Missouri, Arkansas and Red are due to the fact that a large portion of the watersheds is in arid belt. Flood flow comes mainly from the lower courses and the rates probably equal or exceed the Ohio rate. While floods in the lower river are results of fortuitous combinations, and the records reveal no higher results of such combinations than something slightly in excess of 2,000,000 cfs, there is no reason *a priori* to suppose that such may not occur.

(83) Overflow Basins. The river flows along the crest of a ridge built up from its own alluvium. The ground slopes back from the banks at rates varying from 3 to 13 ft to the mile. The trough of the St. Francis Basin is in places 30 ft below the banks of the river. The basins, in the natural state of the river, played an important part in its floods, acting as great reservoirs and bi-passes. (See Paragraph 59.) The total area subject to overflow is shown in the following table:

* While this is the largest officially reported figure, it is altogether probable that it is occasionally much larger.

AREAS OF OVERFLOW BASINS.

Locality	Area by States		Total Area
	State	Area	
St. Francis Basin, from Commerce, Mo., to Helena, Ark.	Missouri Arkansas	2,874 sqm 3,216 "	6,090 sqm
Left Bank, from Commerce, Mo., to Memphis, Tenn.	Illinois Kentucky Tennessee	65 " 125 " 426 "	616 "
White and Arkansas Basins, from Helena, Ark., to Arkansas City, Ark.	Arkansas	956 "	956 "
Yazoo Basin, from near Memphis, Tenn., to Vicksburg, Miss.	Tennessee Mississippi	27 " 6,621 "	6,648 "
Macon, Boeuf and Tensas Basins, from Arkansas City, Ark., to Red River	Arkansas Louisiana	480 " 4,475 "	4,955 "
Left Bank, from Vicksburg, Miss., to Baton Rouge, La.	Mississippi Louisiana	305 " 110 "	415 "
On West Side below Red River	Louisiana	8,109 "	8,109 "
On East Side below Baton Rouge	Louisiana	2,001 "	2,001 "
Total			29,790 sqm

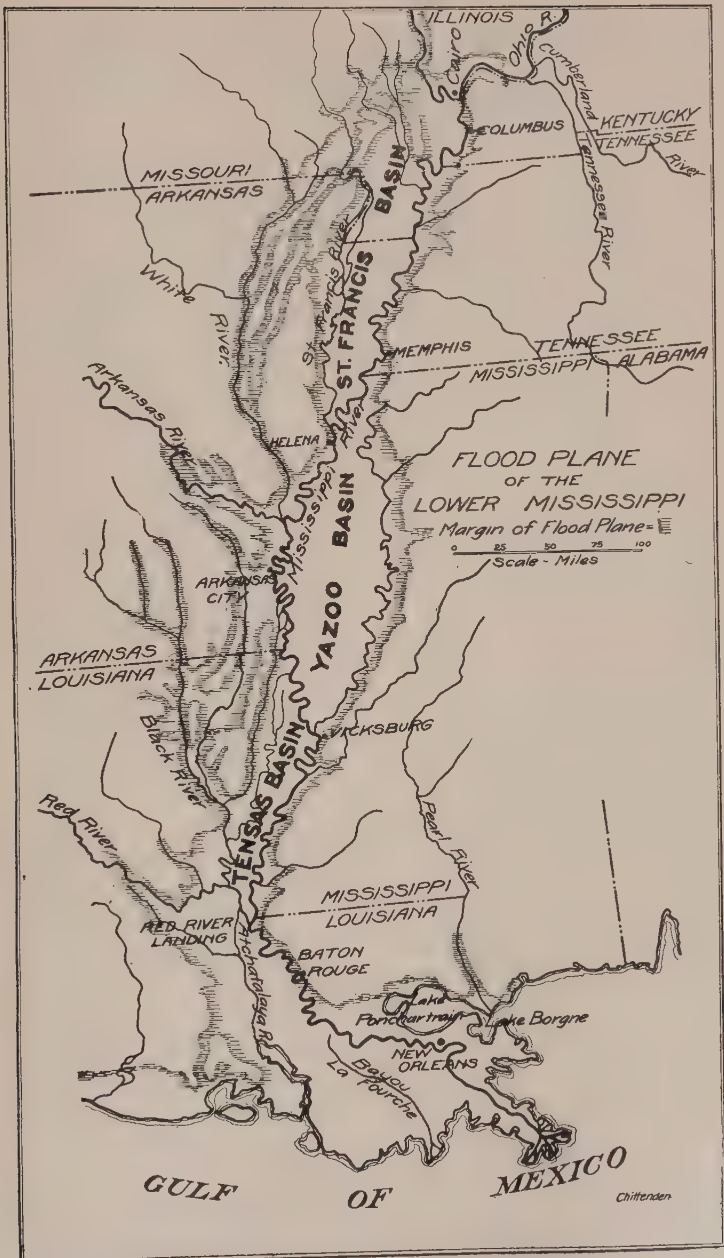

Fig. III. Flood Plain of the Mississippi.

(84) Miscellaneous Data. The following table exhibits some of the more interesting additional data at certain important points along the lower river:

Locality Considered	Distance from Cairo	Flood Stage	Maximum Gauge Height Recorded	Maximum Range between High and Low Water	Maximum (*) & Minimum (†) observed discharges in thousand cfs and corresponding mean velocities in fs		Average Slope in feet per m	
	Miles	Feet	Feet	Feet	Discharges	Velocities	High Water	Low Water
Cairo	0	45	54.7	55.7	2015 71	8.30 1.11		
							.417	.423
Helena	307	42	55.2	58.2	2040 88	8.01 2.44		
							.341	.337
Arkansas City	439	42	55.3	58.9	2006 103	7.80 2.32		
							.331	.312
Vicksburg	600	45	52.5	59.0	1783 97	5.82 2.50		
							.270	.253
Red River Landing	766		53.2	53.8	1595 94	6.78 2.16		
							.178	
Carrolton (New Orleans)	957	18	21.1	22.0	1357 158	7.00 1.10		

(85) Sediment. The Mississippi is a great carrier of sediment. The quantity actually moving in any one section of the lower river is made up of that received at Cairo and from intervening tributaries and that resulting from disintegration of the banks. With the exception of the relatively small loss due to overflow deposit, which the completion of the levee system will practically eliminate, the quantity which passes out into the Gulf is equal to that received into the channel from the outside. Bank caving does not increase this quantity, for otherwise the bottoms would be wearing away, whereas the

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* From Miss. R. Comm. report 1913, p. 3360.

† House Doc. 50, 61st Cong. Last Sess., p. 38. Velocities as high as 15 fs have been observed. Ordinary low water discharge above Arkansas City is about 100,000 cfs. Discharge at bankfull stage is about 1,000,000 cfs. Width of channel at bankfull stages varies from 2,000 to 10,500 ft.

reverse is actually the case. The quantity transported to the Gulf has been estimated at 400,000,000 cyd annually, and the average annual advance of the delta at 260 ft.

(86) The disintegration of the banks through erosion by the current, slumping from saturation, and other minor causes is the most persistent and troublesome characteristic of the river. The extent of this process is almost inconceivable. It was reported in 1892, as a result of surveys, that, in a channel length of 885 mi (1770 mi of bank), there were 921 mi undergoing erosion, or considerably more than half. The amount of this erosion in one year was estimated at 860 sqmf or nearly 900,000,000 cyd. For the most part this prodigious burden is dropped near its origin, filling up depressions or building bars, and the channel section is thus undergoing constant change. The finer sediment has been classified as in "solution" and practically all passes out to the Gulf. Coarser material is carried in "suspension" and is more quickly deposited with velocity reduction, while prodigious quantities drift along the bottom in immense waves, some of those actually measured being 600 to 1000 ft long, 10 to 15 ft high, moving at rates of 15 to 30 ft per day.

(87) The characteristics considered in the last two sections chiefly affect the interests of navigation. They affect the flood problem through the jeopardy in which they place the levee system. Protection from undermining can be secured only by bank revetment, a very costly operation, or by retiring the levees beyond the danger zone, and this is objectionable from a reclamation standpoint. The sediment borne into the lower course of the river may have a bearing on the construction of an outlet for the relief of New Orleans. Such an outlet, it is generally admitted, would afford the needed flood relief and would not injuriously affect the navigable channel; but it is feared that it might soon be destroyed through sedimentation. (See also Paragraph 61.)

(88) Economic Aspect of Problem. Within the margin of the flood plain there is an area of about 30,000 sqm. The portion of this susceptible of reclamation has been estimated at 25,000 sqm or 16,000,000 acres. An average future valuation of $100 per acre gives $1,600,000,000. A future population of

300 to the sqm gives 7,500,000. The mileage of railways crossing this area in all directions, forming parts of interstate systems, is already large and is constantly increasing. The possibility of the development of an empire here greater than the Belgium or Holland of today is absolutely dependent upon protection from the river. This, in briefest statement, is the economic problem of the Mississippi.

(89) Solution of Problem. As was natural, the magnitude and the importance of the problem have suggested many solutions—re-forestation, reservoirs, cutoffs, bi-passes, outlets and levees—but all (if we except a possible outlet near New Orleans) have been rejected except the last. There has been a vast amount of discussion during the past 75 years, but the above conclusion is stronger today than ever among well informed engineers, and the problem will apparently be worked out on a ''levees only'' basis. The levee system began in 1727, soon after the founding of New Orleans. At the time of the Civil War it had been greatly extended and upward of $41,-000,000 spent. The war and intervening floods ruined the levees. Bankrupt communities could not restore them. Congress finally came to the rescue in 1879 by the creation of the Mississippi River Commission. Federal appropriations began, and down to and including 1912 amounted to something over $77,000,000 of which about $32,000,000 has gone into levees and about $17,000,000 into bank revetment. Since the close of the war, local authorities have expended a sum on levee work variously estimated at 65 to 70 million dollars. The result of this work is that nearly the entire river is now leveed on both sides except along bluff shores or where the bottoms are too narrow to justify the cost. Of a total length of 1570 mi requiring levees, 1500 mi has been built. The cubic contents of these levees to the year 1914 was about 275,000,000 cyd. But the work is still far from completion. Based on the revised grade and sections of 1914 the stage of completion is a little more than 60 per cent.

(90) Local Agencies. The proportion of federal to local contribution to the cost of the existing levee system is not very clear from the records. The figures given above indicate a proportion of 1 to 2, but other estimates place it at 2 to 3. The

local contribution is made through the agency of levee districts created under state laws. The most successful of these districts is that embracing the Yazoo Basin, Miss., which for thirty years has been under the chief-engineership of T. G. Dabney, oldest in service of the levee builders of the Mississippi Valley. The levees in this district are of a standard superior to that of the government work, and the reclamation of the basin has added greatly to the wealth of the State.*

(91) Mississippi River Commission. The Government's share of the work has been carried out by the Mississippi River Commission, a board consisting of three engineer officers, one official of the Coast and Geodetic Survey, two civil engineers and one lawyer. It has now had active charge of the work for over thirty-five years and has expended, as stated above, over $77,000,000. An examination of the reports of the Commission must impress anyone with the exceptionally high character of its personnel throughout its existence so far, and with the evident disinterestedness, intelligence and conservatism with which it has handled its great problem. Its efforts have necessarily been experimental in many respects; but this preliminary work is now practically complete, the elements of the problem are well understood, and the data collected and available for use are of the most comprehensive character. Beset with conflicting theories and distracting public criticism whenever great floods have swept down the valley, the Commission has nevertheless held to a steadfast policy and is now thoroughly equipped to carry that policy into effect as rapidly as Congress shall permit it to be done.

(92) Crisis of Problem. While a study of the records carries conviction that the Mississippi River Commission is proceeding along right lines, it also leaves the impression that the

* District organized in 1884; embraces all of 5 and part of 4 counties; taxable area 2,500,000 acres; levee length about 100 miles; maximum tax rate on river frontage 17.5 mills, and on other counties 12.5 mills ad valorem, and a flat tax of 5 cents per acre on whole district; assessed valuation has increased 400 percent; last crevasse in 1897; flood of 1912 necessitated, however, revision of levee standard, about half of which is now completed; no aid from federal government since 1905; district has contributed to bank protection about $400,000. Major Dabney has had charge of the district from its organization.

problem itself is at a critical period in its development. That problem is peculiar in one respect. It is not, as has often been asserted, capable of economic development gradually from small beginnings, as with a great railway system. There comes a time when, in its incomplete state, it may itself be an agency of destruction, and it becomes imperative to bridge over this period of danger with the greatest possible dispatch. This situation arises from the rapid increase of property behind the levees, in large part brought about by the prospect of protection, and from the far greater destructiveness of overflow through crevasses compared with that from the thin flow over the natural banks before levees were built. In illustration of the second point may be cited the case of a railroad which crosses the St. Francis basin, a distance of some 40 miles. Before levees cut off overflow into this basin, little trouble was experienced from floods, for the water spread out with much uniformity and without injurious currents. But in 1912 the overflow came through crevasses, with high velocity and great volume and practically destroyed 15 mi of the line. It is stated that on one railway system alone 450 mi of line was practically out of use for 90 days. An estimate of the losses from floods of 1912 and 1913 gives sums of $40,000,000 and $20,000,000, not taking into account indirect losses. While these were extraordinary floods, there seems to be little doubt that the vast increase of property following the progress of levee construction and the increased destructiveness of overflow through crevasses are mainly responsible for the immense damage. It appears also that loss of life in the late floods was much greater than in former floods. To these losses must be added the heavy outlay for fighting the floods and for repairs of the levees (the government appropriated $1,500,000 for this purpose in 1912) most of which would be unnecessary with a completed system.

(93) Method of Financing. The situation as it now exists seems to make continuous and rapid work on a dependable basis of expenditure more important than it has ever been before. As an economic proposition, the Mississippi problem is second in importance only to that of Panama and it should be handled on much the same general plan; that is, provision should be made for the completion of the levee system in from

5 to 10 years. As posterity will be even more a beneficiary of the work than the present generation, it would seem that the most equitable plan would be to finance the project by a bond issue maturing in, say, fifty years, thus spreading the original cost over that period. It is questionable if the cost can safely be placed below $100,000,000. Considering the vast benefits directly accruing to the lands protected, it would seem that, except in special cases of narrow bottoms, such lands should bear at least half the original cost and the same proportion of the annual cost of maintenance. This would really add but a small sum to the cost per acre of drainage and development while the annual unit charge for maintenance would be trifling. The work of bank protection pertains largely to navigation and its cost will doubtless be borne by the government. It is not necessary in this work, as in that of levee construction, that the whole project be completed in a short time. It may be taken up only as actual necessity develops and its full completion will extend over a long period. It can thus be financed by direct appropriation without imposing an unreasonable burden on the present generation.

II. THE SACRAMENTO PROBLEM.

(94) General Statement. Second in importance to the Mississippi problem only, and even more difficult of satisfactory solution, is that of the Sacramento River, California. The valley of this stream below the mountains is the northern portion of the great open plain extending southeast and northwest through the State of California more than 300 mi. The southern portion of the valley is drained by the San Joaquin River, the two trunk streams flowing directly toward each other to a junction at the extreme upper end of Suisun Bay, which is itself the eastern extremity of San Francisco Bay. The problem here considered relates to that portion of the Sacramento River in the lower 200 mi (channel distance) of its course.

(95) The Sacramento Watershed. The Sacramento River rises in northern California in the vicinity of Mt. Shasta and drains the western slope of the Sierra Nevada and the eastern slope of the Coast Range for an air line distance north and south of 220 mi. It emerges from the mountains into the flood

plain at Red Bluff, the lowest point at which the stream is confined within banks at all stages. The principal tributaries on the east are the Feather River (with its tributaries Yuba and Bear Rivers) and American River; on the west are Stony, Cache and Puta Creeks. The watershed areas are as follows:

Main stream above Red Bluff		9,300 sqm
Feather above Oroville	3,640 sqm	
Yuba above Smartsville	1,220 "	
Bear	263 "	
		5,123 "
American River		1,910 "
Stony Creek		601 "
Cache Creek		1,230 "
Puta Creek		805 "
Unmetered foothills		3,907 "
Unmetered valley lands		4,250 "
Total		27,126 "

(96) The Flood Plain. The area subject to overflow in high flood begins at Stony Creek, and comprises about 1700 sqm, or 1,088,000 acres, including channels, ponds, irreclaimable marsh and some islands near the outlet. The probable area susceptible of reclamation, if the river were held to its channel, is 900,000 acres more or less. The land is very rich and is worth under cultivation $100 to $500 per acre. The area is divided into "basins" which form reservoirs in flood time. These are specified in the following table with areas and storage capacities to the level of the 1907 and 1909 floods. The Sacramento basin which lies on the east side of the river south of American River, is omitted as being without storage capacity of great extent and partly tributary to the San Joaquin system. (See map.)

Name of Basin	Area in Acres	Storage Capacity in Million cf
Butte	54,000	17,730
Sutter	116,000	45,215
Colusa	93,000	38,333
American	70,000	24,873
Yolo	140,000	49,049

(97) Precipitation and Runoff. The rainy season in this region extends from November to April. The course of storms is usually inland from the coast in a northeasterly direction. The precipitation is heavy in crossing the Coast Range, much lighter in passing over the Sacramento Valley, and heaviest of all on the slopes of the Sierra. The mean annual precipitation in the Sacramento basin varies from 15 in in the south to 20 in in the north. In the foothills precipitation attains as high a figure as 100 in. In ten days (March 17-26) during the flood of 1907, the total precipitation on the Puta Creek watershed is believed to have not been less than 20 in and on the American River watershed 15 in. The heavy snow blanket in the Sierra, however, gave a higher actual rate of runoff than on the treeless watersheds of Puta Creek. The rate of runoff on the several tributaries varies greatly. On the Sierra slope, rates of 50, 60, and even 100 cfsm were recorded, while for the whole watershed of 27,000 sqm it reached a figure of 23 csfm. This is a very high rate for so large an area. It is true that it was equaled in Pittsburg's greatest flood, but the watershed above Pittsburg is only two-thirds as large, and there is no extensive area of flat country, like the Sacramento flood plain.

(98) Discharge and Channel Capacity. These enormous runoffs impose a tremendous duty on the trunk channels, a duty which they have never been able to perform. In their natural state they everywhere below the foothills overflowed their banks. The following table exhibits the estimated combined discharges at various points on the main stream for the flood of 1907 and the actual channel capacities:

Locality	Distance from Collinsville*	Present Channel Capacity	Estimated Discharge, 1907 Flood, if confined to channel
Stony Creek	202 mi	235,000 cfs	235,000 cfs
Colusa	151 "	70,000 "	250,000 "
Knights Landing	94 "	25,000 "	250,000 "
Feather River	81 "	65,000 "	450,000 "
American River	62 "	80,000 "	525,000 "
Cache Slough	16 "	165,000 "	600,000 "

* Collinsville is at the point where the Sacramento empties into Suisun Bay.

(99) Mining Debris. Unusual conditions on the east side tributaries aggravate this situation. Debris from hydraulic mining has completely changed the character of the Yuba River, filling its channel 80 ft at Smartsville, 20 mi from the mouth, 11 ft at the mouth, and to a less extent the Feather and the Sacramento. The same is true to some degree of the Bear and American Rivers. While this condition has a bearing on flood control its effect upon navigation is much more important.

(100) Magnitude of Problem. The figures above given demonstrate the magnitude of the Sacramento flood problem in its main purpose of reclaiming the bottom lands from overflow. The channels have never been able to carry even ordinary floods. The basins have performed the double purpose of reservoirs and bi-passes and the runoff has found its way into the Bay in volumes rarely, if ever, exceeding 200,000 cfs on the main stream below Cache Slough. How to control this enormous overflow is a question which engineers have been trying for more than half a century to solve.

(101) Proposed Solutions. Two divergent views have been held as to the proper method of handling the problem—one, the levee system which would concentrate the flow of the river between levees on its immediate banks; the other, the bi-pass system which accepts Nature's method of dispersion of flood waters, and would change it no further than to set some bounds to the area of dispersion. The concentration, or levee, system was first advocated by William Ham Hall, State Engineer, and a board of consulting engineers (1880) consisting of General Alexander and Colonel Mendel, Corps of Engineers, and James B. Eads; and by the Dabney Commission of 1904, so-called from its chairman, T. G. Dabney, the veteran levee builder of the Mississippi. The bi-pass method was first formulated in 1894 by C. E. Grunsky and Marsden Manson, and was adopted in more elaborate form in 1910 by the California Debris Commission, a Federal board composed of officers of the Corps of Engineers, originally created to regulate hydraulic mining as it affected the navigable waters of the United States.

(102) The Concentration Plan. Prior to 1904 available data indicated a maximum flood discharge below Cache Slough of 250,000 cfs. It was believed by the Dabney Commission that

this could be eventually, but not as a first measure, confined within levees, supplemented with radical channel enlargement. Owing to the extremely mobile character of the bed, and the greatly increased flood velocities, current scour was relied upon to do a large part of the work of excavation. As a long time would be required for this purpose (twenty years, or more), a temporary bi-pass was provided along the west side, with numerous overflow weirs from the main stream, the bi-pass to be gradually contracted as experience might justify, and eventually to become a drainage canal. As a natural corollary of a scheme which involved the sluicing of such vast quantities of silt into tide-water, it was expected (and desired) that Suisun Bay would rapidly fill up. As it is already too shoal for navigation, its manifest destiny is reclamation, and anything which would hasten the addition of so important an area to the agricultural resources of the State seemed worth considering.

(103) The Bi-pass Plan. The great floods of 1907 and 1909 proved that the discharge of the lower Sacramento might reach a figure of 600,000 cfs. This manifestly could never be confined within levees at any admissible cost and the bi-pass plan came up again, and was formally recommended for adoption by the Debris Commission. Its controlling feature is a bi-pass of sufficient capacity to carry the great bulk of the discharge. It begins on the east side of the river about 36 mi below Stony Creek, descends Butte and Sutter Basins, crosses the main stream just above the mouth of Feather River, descends Yolo Basin, and rejoins the main stream at Cache Slough. Above Stony Creek and below Cache Slough, the flow is to be confined to the main channel—in the upper reach by levees and in the lower chiefly by excavation. On Feather River the levees are to be so far apart as to make the river virtually a bi-pass. Great overflow weirs are to be provided at the head of the bi-pass (Moulton Weir), at the crossing of the Sacramento River just above Feather River (Freemont Weir), and a little above the mouth of American River (Sacramento Weir). A smaller weir (Tisdale) is located about midway of Sutter Basin. Above the Sacramento crossing (near the mouth of the Feather River) the bi-pass has a width varying from 1900 to 4100 ft. The width through the Yolo Basin varies from 8000

to 12,000 ft. The Moulton Weir is to be 2840 ft long; the Fremont Weir 8000 ft long; the Sacramento Weir 1670 ft long; and the Tisdale Weir 1140 ft long. Both the rivers and the bi-passes are to be leveed, the grade to be 3 ft above flood height except on the lower Yolo bi-pass where, on account of exposure to wave wash, the height is 6 ft. Below Cache Slough the channel is to be rectified and enlarged to carry 600,000 cfs.

(104) Comparison of Plans. Such are the main features of the two systems and a comparison in detail will be of interest.

(a) The levee system involves a radical enlargement by levees and excavation of the main stream so as ultimately to carry the flood flow as estimated in 1904; the bi-pass plan provides an auxiliary channel for the main discharge, leaving the trunk stream practically as it is so far as discharge is concerned, with two places where in high flood the current is actually reversed.

(b) The levee plan contemplates a radical departure from Nature; the bi-pass plan a close adherence thereto.

(c) The levee scheme gives reclamation first consideration; the bi-pass plan navigation. The difference as to reclamation is 60,000 acres in favor of the levee system.

(d) Both plans contemplate carrying the whole flow in the trunk stream below Cache Slough.

(e) Both plans contemplate the collection of upland drainage so as to keep it out of the basins and conduct it to the main stream or to the bi-passes at selected points.

(f) Both plans provide a relief canal for Colusa Basin through Knight's Landing ridge.

(g) Both plans make use of cutoffs, but the levee plan to much the greater extent.

(h) Both plans provide for the mechanical removal of water from low parts of the basins during flood.

(i) The levee plan contemplates the ultimate elimination of basin storage; the bi-pass plan retains so much as falls within the bi-pass levees.

(j) Both plans accept the principle of limited relief by reservoirs on the headwaters.

(k) The levee plan contemplates the filling up and reclamation of Suisun Bay; the bi-pass plan favors its preservation as nearly as possible in its present condition.

(l) The levee plan contemplates the permanent closing of the two natural outlets into the San Joaquin, Georgiana and Three-Mile Sloughs; the bi-pass plan is non-committal on this point.

(m) The levee project was estimated to cost $24,000,000; the bi-pass project $33,000,000.

(n) Considering the temporary bi-pass provision of the levee plan, the two systems would not radically differ in initial operation, but the fundamental distinction is, that the levee system looked forward to the ultimate reclamation of all the valley above Carquinez Straits, while the bi-pass plan accepts as a permanent arrangement a much less extensive scheme of reclamation.

(105) The Question Settled. As a proposition for controlling such floods as those of 1907 and 1909 the levee scheme is, of course, impracticable. Those floods, however, were wholly exceptional, the nearest approach to them being, apparently the flood of 1862. With the temporary bi-pass provision in the levee plan, and with ample overflow weirs in the levees, a flooding of the basins once in a generation on the average would probably be a much smaller loss to the State than the sacrifice of 60,000 acres of land susceptible of reclamation. Be that as it may, however, the question is now definitely settled in favor of the bi-pass system. The project has been adopted by the State of California in its entirety, and by the United States so far as to commit the Government to about one-sixth of the original estimate of cost. The rest of the cost will be financed by local interests. A portion of the work is being done by private enterprise in the reclamation of certain lands, their work conforming, so far as it goes, to the official project. The main reliance, however, is to be a large assessment district, officially known as the Sacramento and San Joaquin Drainage District, created by Act of State Legislature. For the general control of the local work there has been created, Act of 1913, The Reclamation Board of California, consisting of seven members. The engineering work of this board is under a Flood Con-

trol Engineer. The State has taken hold of the enterprise with earnestness and enthusiasm, and the vexed problem seems to be in a fair way to early solution.

III. THE PITTSBURG PROBLEM.

(106) General Statement. The Pittsburg flood problem is the most important in the United States in which a single city is the chief interest concerned and in which the chief reliance for protection, so far proposed, is an extensive reservoir system. In area of overflow the problem is quite insignificant, but owing to the intensive character of development of this area, interference by overflow is a matter of very grave concern. Pittsburg, situated where the Allegheny and Monongahela unite to form the Ohio, is one of the greatest, if not the greatest, industrial center in the United States. The topography is so abrupt and hilly that railroads, industrial plants, and commercial houses connected therewith are forced into the narrow bottoms subject to overflow at every considerable freshet. These freshets are of frequent occurrence and the resulting losses are becoming so serious, that a remedy for the condition must be found in the near future. An elaborate investigation, costing about $125,000, was made in 1910-1911 by a voluntary organization known as the Pittsburg Flood Commission, and a voluminous report, discussing possible methods of relief, and presenting definite recommendations, was submitted April 16, 1912. The following data are mainly derived from this report.

(107) The Watershed. The watershed above Pittsburg comprises an area of 18,920 sqm of which 11,580 sqm is on the Allegheny and 7340 sqm on the Monongahela. The topography is mountainous, the slopes steep, the soil "impermeable" except in the northern portion which is covered with glacial drift. The surface is generally one of quick runoff and the streams develop sharp flood peaks. The watershed is oblong shaped, being 60 to 70 mi wide east and west, by 300 mi north and south. Storms pass over it usually in an easterly direction rarely affecting simultaneously the whole area, and as a consequence the flood peaks from the two main tributaries rarely arrive at Pittsburg at the same time.

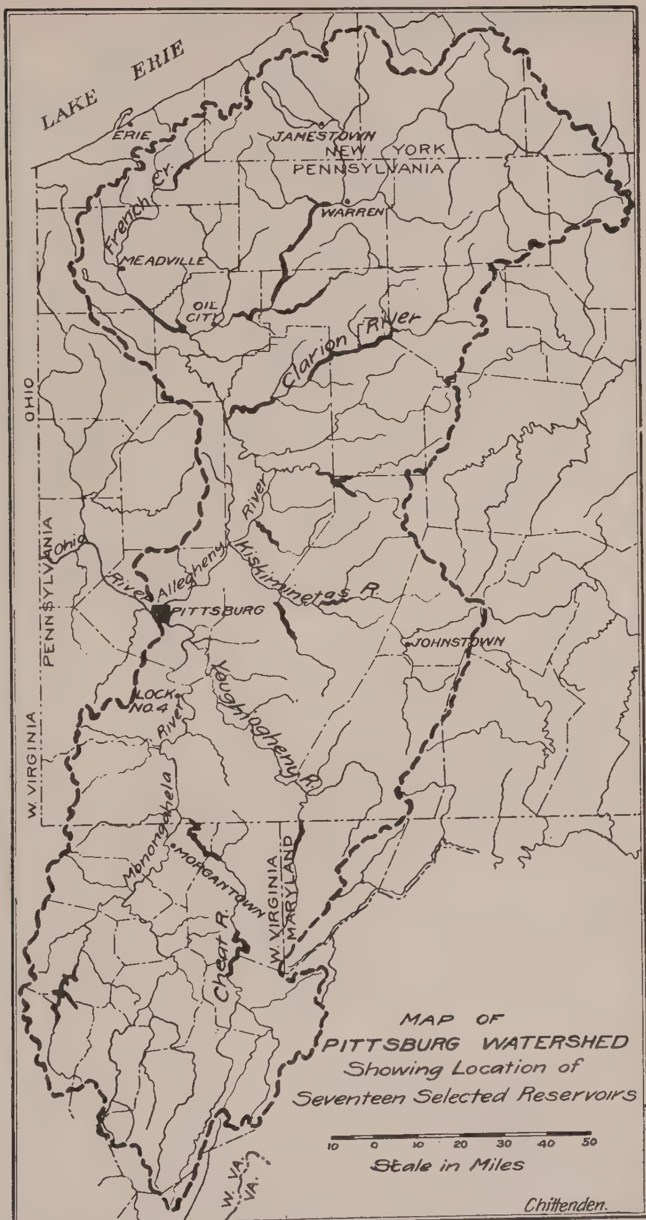

Fig. V. Watershed above Pittsburg.

(108) Slopes and Distances.

	Distance mi	Slope ft per mi
Allegheny River		
From near source to Oswayo Creek	52.0	15.0
" Oswayo Cr. to Conewango Cr. (Warren)	69.0	3.7
" Conewango Cr. to French Cr.	65.4	3.3
" French Cr. to Clarion Cr.	40.5	2.6
" Clarion to Kiskiminitas	56.0	2.0
" Kiskiminitas to Pittsburg	30.0	1.1
Monongahela River		
Mingo Flat near source of Tygart River to Beverly	30.0	23.3
Beverly to Buckhannon R.	35.0	19.1
Buckhannon R. to West Fork (Fairmont)	50.0	9.2
Fairmont to Cheat R.	37.0	2.1
Cheat R. to Lock 4	49.0	1.2
Lock 4 to Pittsburg	42.0	0.5

(109) Precipitation. Rainfall records are available from 84 stations, of which 50 have been kept for 20 years or more. The Pittsburg record extends over 70 years. Following are the annual means:

	Allegheny	Monongahela
Mean annual of all stations	42.4 in	45.5 in
Mean annual, lowest at any station	22.3 "	19.1 "
Mean annual, highest at any station	59.7 "	80.9 "

The records show that the monthly rate has exceeded 10 inches 60 times and that in several instances it has exceeded 15 in. July is the month of heaviest rainfall, but owing to high temperature and the intermittent character of storms, floods rarely result. The annual snowfall is about the same on the two watersheds but remains much longer on the Allegheny and often contributes materially to the intensity of runoff. In 1910 the fall at certain points amounted to 112 in. The heavy general rains, low temperatures and presence of snow in winter are the principle causes of floods, some 60 per cent of which occur in the period from January to March inclusive.

(110) Runoff. The rates of runoff, both on the main stream and tributaries are high. The maximum for the whole watershed is 23 cfsm; for the Allegheny 26 cfsm; for the Monongahela at Lock 4, 41 mi above Pittsburg, 38.1 cfsm, while on some of the main tributaries it considerably exceeds 50 cfsm.

The maximum discharge of the Allegheny at Pittsburg is 300,000 cfs; of the Monongahela about 240,000 cfs; but the highest recorded combined discharge is only 434,000 cfs. The flood stage at Pittsburg is 22 ft. This was passed 78 times from 1806 to 1912. The 30 ft stage has been passed 15 times. The highest stage yet reached (1907) was 35.5. It is considered entirely probable that a 40 ft stage may be reached. The flood peaks are sharp and of short character. The river has once remained above flood stage for 86 hours, but it generally subsides within 50 hours, and frequently in much less time. The two most dangerous flood tributaries, because of their proximity to Pittsburg, are the Kiskiminitas (1877 sqm) which enters the Allegheny 30 miles above the mouth; and the Youghiogheny (1732 sqm) which enters the Monongahela 15.6 mi above the mouth. The slopes of these streams are steep, the rate of runoff high, and their watersheds being contiguous, are usually covered by the same storms.

(111) Channel Encroachment. It is estimated that the channel widths have been encroached upon by riparian owners to the extent of 17 per cent on the Allegheny and 30 per cent on the Monongahela. The present average widths are: Ohio River 1385 ft, Allegheny 770 ft, Monongahela 860 ft. There are numerous bridge piers, and the channel section has been restricted somewhat further by works in aid of navigation.

(112) Property Values and Losses. The area subject to overflow in an extreme flood like that of 1907 is about 1540 acres of which approximately 866 acres is devoted to industrial use, 435 acres to railroads, and 192 acres to mercantile and residence use. The assessed value of the overflow area was, in 1910, about $160,000,000 and it is estimated that this would be increased by $60,000,000 as a result of adequate flood protection. The direct losses from the flood of 1907 were estimated at $5,250,000.

(113) Measures of Relief Considered. The Flood Commission considered three distinct measures of complete or partial relief, and also combinations of two or more of these. The first two were protective measures only, accepting the floods as they come and seeking protection from them. They were (a) channel enlargement by excavation, and (b) channel enlarge-

ment by levees (in this case, vertical masonry walls). The third measure was in the nature of flood prevention, and sought to reduce the flood heights themselves by an extensive reservoir system on the watershed.

(114) Channel Enlargement. Under this head, two grades for excavated channel bed were considered, one being 3.7 ft below the other. They were estimated to lower extreme floods by 2.3 and 3.7 ft at costs of $852,700 and $3,054,000 respectively. The results were considered incommensurate with the cost, and in any event as falling far short of the desired relief.

(115) Levees. (Vertical Wall). It was found that complete protection from a flood like that of 1907 could be had by the construction of a levee wall. That proposed was to be built to elevation 37.5 with a parapet reaching to 41. The cost was estimated at $14,288,700 after deduction of reclaimed land. This method involved grave objections from an operative standpoint, because of grades and the difficulty of passage from one side of the wall to the other. Moreover it left flood heights as great as before, resulting in sewerage difficulties and interference with the passage of boats under bridges after the river had reached a certain stage.

(116) Reservoirs. The drawbacks just referred to made it extremely important to accomplish, if possible, a lowering of the flood heights themselves, and this naturally led to an investigation of reservoir possibilities. The sharp, short flood peaks indicated that reservoirs would be particularly effective in this situation, as the quantities represented by the overflow stages were not so great as to absolutely preclude the possibility of storage. The subject was exhaustively studied. Forty-three sites were examined, of which seventeen were selected as sufficiently effective to be further considered. An elaborate analysis of the effect on the Pittsburg flood peak in eleven floods was made. The conclusion was reached that the system would have held the peak below the flood stage in all but three floods, in which three it would have passed the flood stage by 0.8, 2.2 and 6.7 ft respectively. The cost was estimated at $21,672,100.

(117) Project Recommended. The commission finally recommended the adoption of the 17-reservoir project with a

wall of sufficient height to hold out the occasional excess above the flood stage. Adding the cost of the wall and deducting the value of reclaimed land and certain "island revisions", the final estimate of cost was $20,035,100, or $5,746,000 more than the cost of protection by the wall alone. But it was considered that the advantages of lowered flood height, lower wall, and protection to the valleys above and below justified the greater expense. Owing to the great preponderance of local interests affected, the project will naturally be mainly financed locally; but federal interests involved are sufficient to justify limited government aid.

(118) Comments. Taking everything into consideration, the Commission's view that reservoirs furnish the true solution of the Pittsburg flood problem seems entirely sound. The situation is one where nothing but actual reduction of flood height will accomplish the full purpose desired, and such reduction can be secured only by the use of reservoirs. It is not likely that the full estimated results, either in flood reduction or in cost, will be realized. The reservoir sites are far from ideal, and subsequent investigations by a government board indicated a deficiency in cost estimates. But even if the estimated results are subject to a considerable discount, the principle itself will still hold good. There are few flood problems to which it is so directly applicable. It is greatly to be desired that the scheme be fully tried out. Not only would it give Pittsburg a large measure of relief, but the effect of the example, in settling many disputed theories, would be of great value to the engineering profession and the country at large.

IV. THE DAYTON PROBLEM.

(119) General Statement. The problems so far considered deal with conditions of frequent recurrence. The Dayton problem arose from an occurrence entirely unprecedented. The appalling calamity of March, 1913, in the valley of the Great Miami River stirred public sentiment deeply and led to the most thorough study of the problem involved that has ever been given to any work of its importance. The loss of life in the flood was upward of 400 and the loss of property nearly $70,000,000, while indirect losses from interruption of trans-

portation and from other causes would greatly increase the figure. Under the auspices of the Dayton Flood Prevention Committee, a preliminary fund of $2,000,000 was raised and upward of $200,000 has been expended on surveys and investigation. A special act was procured from the State Legislature, entitled The Conservancy Law of Ohio, and plans have been perfected for construction work as soon as certain legal opposition has been overcome. The active agency, in carrying out the work has been the Morgan Engineering Company of Memphis, Tennessee, Mr. Arthur E. Morgan, President. The following data are condensed from their voluminous studies.

(120) The Watershed. The area of the watershed of the Great Miami River (hereafter referred to as the Miami River), exclusive of the Whitewater River, Indiana, which enters the Miami just above its mouth, is shown in the following statement:

Miami River above proposed Taylorsville dam	1,120	sqm
Mad River above lower proposed reservoir	630	"
Stillwater River above proposed dam	620	"
Additional area above Dayton	162	"
Total area affecting Dayton	2,532	"
Twin Creek above proposed reservoir	280	"
Total area above Hamilton	3,548	"

The watershed is generally rolling and without precipitous slopes. It is compact in form, roughly a square above Dayton about 50 mi on a side. It is thus liable to be simultaneously affected in all its parts in nearly equal intensity by any general storm.

(121) Slopes.

Miami—Source to Loramie Creek		3.0 ft per mi
Miami—Loramie Creek to Dayton		3.5 " " "
Miami—Dayton to Twin Creek		3.3 " " "
Miami—Twin Creek to S. line Butler Co.		4.0 " " "
Miami—South line Butler Co. to mouth		2.9 " " "
Lower Mad River	(about)	6.7 " " "
Lower Stillwater River	"	5.2 " " "
Twin Creek		8.8 " " "
Wolf Creek (entering at Dayton)		17.1 " " "
Other tributaries vary from	4.0 to	24.0 " " "

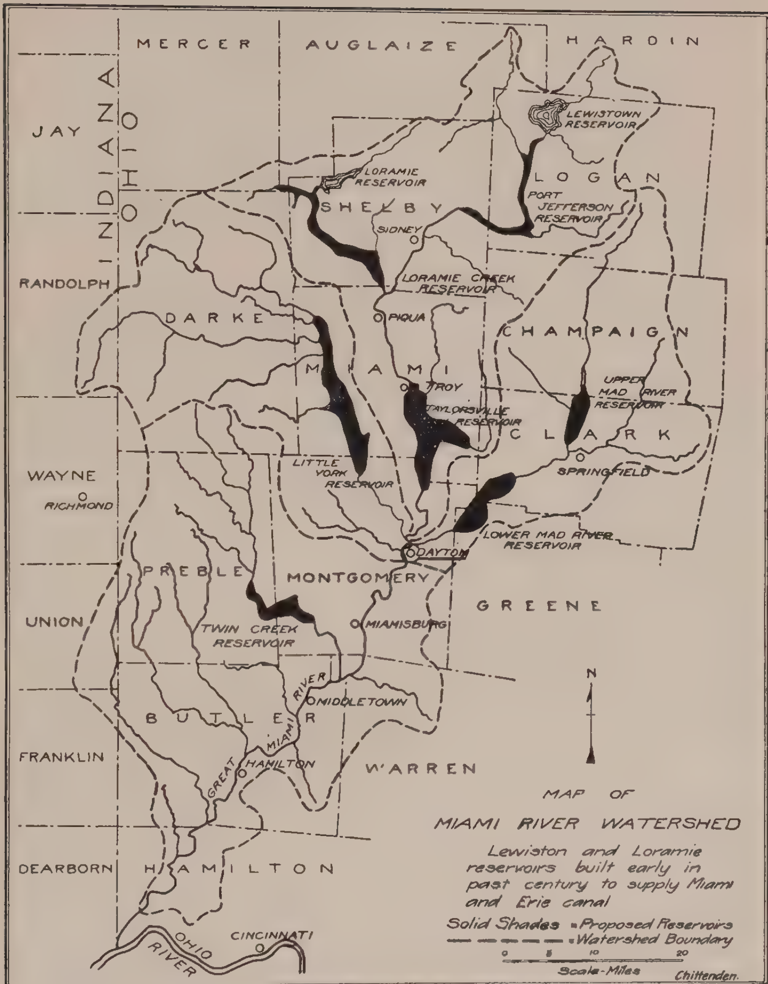

Fig. VI. Watershed of the Great Miami River.

Note that the slope of the Miami is very uniform from the source to Hamilton averaging a little more than 3 ft and being smallest near the source, contrary to the almost universal habit of streams.

(122) Bottom Lands. The submersible bottom lands of the main stream vary from 400 to 19,000 ft in width. The total area is about 100,000 acres. The population of the towns on the bank of the stream is about 200,000, Dayton and Hamilton being the largest with 116,000 and 35,000 respectively. Dayton is situated where the main stream and the two principal tributaries come together.

(123) Storm of March, 1913. The great flood of 1913, which led to the present relief project, was the result of a storm extending over the five days March 23-27, 1913. The average depth of rainfall in this period, over the entire area above Dayton, was 8.8 in. The storm was largely concentrated in the latter part of the 24th and the first part of the 25th during which time 4.25 in fell. The runoff seems to have reached the main stream almost simultaneously everywhere above Dayton, there being no well defined flood wave, but a general rise all along. It reached the following rates on the main stream and important tributaries: Miami above the mouth of the Mad and Stillwater Rivers 113 cfsm; Miami at Dayton (including the Mad and Stillwater) 117 cfsm; Miami at Hamilton over 100 cfsm; Stillwater River 130 cfsm; Mad River 117 cfsm; Twin Creek 244 cfsm, and small east side streams above Dayton much higher rates, there being one stream which reached the figure of 571 cfsm. These rates are believed to be without precedent on so extensive a scale. The flood developed with great rapidity, came as a complete surprise, caught the population unprepared and unwarned, and wrought terrible destruction. Through Dayton the water flowed with terrific velocity to a depth reaching the second story windows of a large part of the business section of the city. The river was above the flood stage at this point (18 ft) about 60 hours and reached a maximum elevation of 29 ft.

(124) Discharge and Channel Capacities. The following table demonstrates the complete inadequacy of the channel of

the Miami to perform a duty like that imposed upon it by the flood of 1913.

Locality	Channel Capacity cfs	Discharge 1913 Flood cfs
Sidney	12,000	44,000
Piqua	25,000	70,000
Troy	20,000	109,700
Dayton	80,000	250,000
Below Miamisburg	35,000	257,000
Hamilton	100,000	354,000
Below Miamitown	20,000	384,000

The channel capacities above and below the several towns are much less than through the towns themselves where they have been extensively modified by artificial means—an excellent example of the point brought out in Paragraph 27 that the general effect of man's operations upon stream channels is to improve their carrying capacity.

(125) Method of Relief Proposed. The figures in the above table demonstrate the utter impossibility of securing relief from such a flood as that of 1913 by any form of channel enlargement. This led to a consideration of the reservoir system as the only possible complete solution of the problem. The watershed was thoroughly explored and it was found that the necessary sites were available; but being all in rich agricultural valleys, the permanent withdrawal of the necessary areas was deemed impracticable. Hence it was decided to adopt the detention system which would leave the basins practically as useful for agriculture as at present. Seven sites were selected of which six are above Dayton. The dams are to be provided with permanent openings carefully apportioned to a definite outflow at the maximum head. The following table exhibits the more important features of the proposed system as finally worked out:

TENTATIVE DATA ON RESERVOIRS.

Name of Reservoir	Catchment Area in sqm	Elevation Max. Flow Line 1913 Flood	Elevation Top of Dam	Storage Capacity to Max. Flow Line 1913 Flood		Storage Capacity to 5 ft below Top of Dam		Area Submerged Max. Flow Line 1913 Flood	Diameter Outlet Tunnels ft	Elevation Bottom River	Maximum Height of Dam
				Millions cf	Inches on Watershed	Millions cf	Inches on Watershed				
Port Jefferson	*(357) 457	980	995	1024	1.0	3290	3.1	Acres 2900	2 Tunnels 25.9	945	50
("Loramie Creek") Lockington	*(174) 255	937	955	2968	5.0	6063	10.2	3900	13.0	879	76
Taylorsville	*(424) 1136	815	835	7020	2.7	15,775	6.0	10,000	2 Tunnels 25.3	756	79
("Little York") Englewood	651	870	893	11,578	7.6	18,100	12.0	7200	11.1	770	123
("Twin Creek") Germantown	270	810	830	3866	6.2	6274	10.0	3300	13.5	723	107
Upper Mad River	324	946	967	4633	6.2	9890	13.1	5600	12.9	895	72
Lower Mad River	*(347) 671	817	835	2287	1.5	5498	3.5	4200	2 Tunnels 21.7	775	60

* Catchment area below upper dams.

Note: Tunnels are horse-shoe shaped with diameter and height approximately equal.

(126) System in Operation. It is estimated that, in a flood like that of 1913, the proposed reservoir system would reduce the discharge at Piqua from 70,000 to 40,000 cfs; at Dayton from 250,000 to 85,000 cfs, and at Hamilton from 354,000 to 120,000 cfs. To carry these greatly reduced discharges will still require some channel improvement, but nothing involving great difficulty or expense. The cost of the complete project is estimated at about $20,000,000, which is to be raised through the medium of an assessment district to be organized under the Conservancy Law of Ohio referred to in Paragraph 119.

(127) Comment. Great opposition has developed to the plan among the rural districts above Dayton. There is a feeling that they are to be taxed for the benefit of Dayton and Hamilton, and there is also a genuine fear of the proposed reservoirs. The project is by no means yet assured of success, but it is to be hoped that it may succeed, for it is certainly one of the most carefully-worked out plans ever undertaken. Its successful completion would be of great value not only to the Miami Valley, in protecting it from future floods, but to the country at large as an example of civic enterprise and as a genuine contribution to the science of flood control.

V. THE COLUMBUS PROBLEM.

(128) General Statement. Columbus, Ohio, on the Scioto River, was another of the many towns in Ohio and Indiana that were caught in the same storm which wrought such havoc at Dayton. The direct property damage is estimated at $5,622,000 and the loss of life at 93. While the disaster itself was of far less magnitude than that at Dayton, and no greater in proportion to the interests at stake than in many other places affected by the same flood, the situation is of interest because of the fact that the "cutoff" method is the main feature recommended for providing relief. An exhaustive study of the situation was made soon after the flood by Alvord and Burdick of Chicago, who submitted a report to the city of Columbus, September 15, 1913. The following data are taken from this report.

(129) Miscellaneous Data. The Scioto River passes through the city of Columbus from north to south. Almost in the heart of the city it is joined by a considerable tributary, the Olentangy, which flows for 40 mi nearly parallel to the Scioto at an average distance of about 5 mi therefrom. The watershed areas are: the Scioto 1050 sqm; the Olentangy 520 sqm. The average slopes of the two streams for 40 mi above their junction are: Scioto about 4 ft per mi; Olentangy 5 ft. The rainfall in March 23-27, 1913, averaged for the Scioto watershed 9.34 in, for the Olentangy watershed 8.74 in; for the entire watershed 9.14 in. The resulting discharges and rates of runoff were: on the Scioto above the mouth of the Olentangy, discharge 80,000 cfs, rate 76 cfsm; on the Olentangy, discharge 60,000 cfs, rate 115 cfsm; on the Scioto below the mouth of the Olentangy, discharge 140,000 cfs, rate 89 cfsm. The moderating influence of what was once the Great Scioto Swamp at the head of that stream, and which operated effectively as a detention reservoir in this flood, accounts for the smaller rate from a higher rainfall as compared with the Olentangy. As it was, the discharge reached a volume far beyond the capacity of the channels and the bottoms through the city of Columbus were completely submerged with great damage to property and loss of life.

(130) Remedy Proposed. Alvord and Burdick submitted ten projects for relief, embracing channel enlargement, complete or partial diversion, detention reservoirs on the two streams, and in all a general use of strong levees. Some of the projects were based on an assumed flood discharge of 200,000 cfs; others of 150,000 cfs. The plan considered most advantageous, and later approved by a Board of United States Engineers, was that designated as No. 7 in the Alvord-Burdick report. It contemplates the complete cutoff of the big bend of the Scioto below the Olentangy beginning near the mouth of the latter stream and terminating at Mound Street. The new channel is to be flanked by massive levees, in some places 100 ft wide and 12 ft above high water. Street grades in the low bottoms are to be raised materially with gradual slopes leading to the levees. The new channel is to be free of obstructions, except bridge piers, and the banks smooth and free of irregularities. The cost was estimated at $11,263,000.

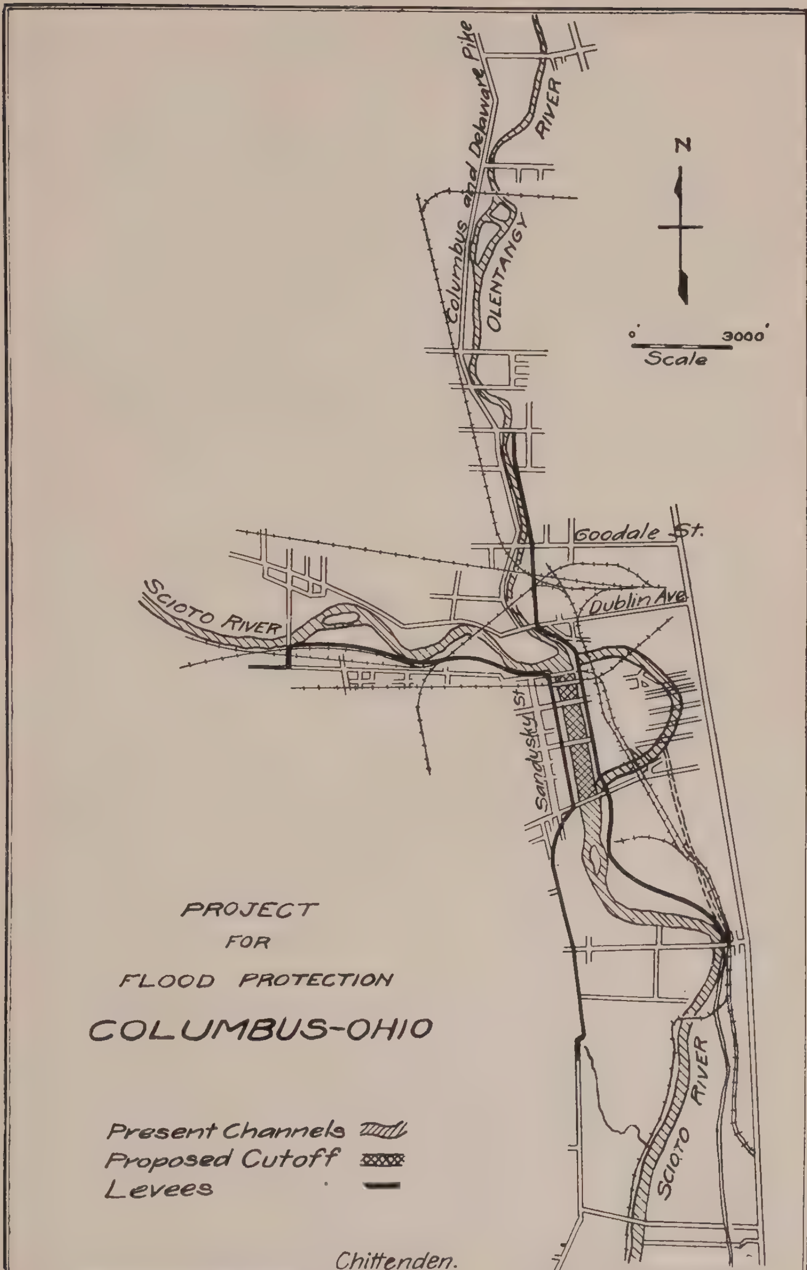

Fig. VII. Flood-Control Project for Columbus, Ohio.

(131) Comment. This study is instructive, not only as a striking use of the cutoff method, but because advantage is to be taken of the opportunity created by an emergency measure to accomplish a much needed reform in the physical status of the city. Among the incidental advantages, apart from flood relief, which will result from the project, if carried out, will be a shorter length of river in the city, with shorter length of levees to maintain, a considerable gain of valuable land, a large reduction in the number of bridges, a marked improvement in traffic conditions, improved sewerage of the low bottoms, and improvements of general appearance through the creation of parking strips. It will be greatly to the advantage of the city in many ways if this comprehensive project is carried out. The contrary policy is well illustrated by the example next to be considered.

VI. THE KANSAS CITY PROBLEM.

(132) General Statement. "West Bottoms" is a term used locally to designate the bottom lands of the Kaw River for a distance above its junction with the Missouri River, but within the limits of the two Kansas Cities (Missouri and Kansas). Owing to the hilly topography and the close crowding of the bluffs upon the banks of the rivers these bottoms have become the locus of the commercial, railway and industrial activity of this very important center. The Kaw Valley, being in prolongation of the westerly course of the Missouri from St. Louis to Kansas City, has become a trunk route west for important railway systems. The situation is similar to that at Pittsburg, and interference with the intense activities prevailing there is quite as important. The bottoms are occasionally flooded from the Missouri, but not to great extent and mainly as backwater without much current. The real flood problem pertains to the Kaw River and dates from 1903 when a flood occurred unequaled since 1844, resulting in the loss of 19 lives and upward of $30,000,000 direct damage, with immense indirect loss through interference with business and the interruption of traffic. The problem is interesting, not only for its intrinsic importance, but as an example of the obstacles of divided jurisdiction discussed in Paragraph 74.

(133) Rainfall and Runoff Data. The area of the Kaw River watershed is about 58,000 sqm, but at least half of it is in the arid or semi-arid belt. The high floods originate mainly in the eastern portion. Such was emphatically the case with the great flood of May and June, 1903. The normal rainfall for the month of May at 10 selected stations in the eastern two-thirds of the watershed, was at that time, 4.5 in. In 1903 there fell between May 1 and 21 the full normal for the whole month. In the next five days there fell 3.4 in and in the following five days 4.7 in. While these are not excessive rainfalls compared with those of other localities—the Sacramento or Miami watersheds, for example—they were excessive for the Kaw watershed and the river channel was wholly lacking in capacity to carry the unusual runoff thrust upon it. The discharge at Kansas City was probably between 300,000 and 350,000 cfs. The rate for the whole watershed, considering the larger estimate of discharge, was only about 6 cfsm, but it was undoubtedly three or four times this on the eastern portion.

(134) Channel Capacity. The capacity of the Kaw River channel near the outlet was, in a state of nature, quite inadequate to carry so great a discharge. But even this limited capacity was not available. Kansas City affords the most conspicuous example within the writer's knowledge of reckless encroachment upon the channel of an important stream. Bridge piers were built on piles cut off at low water and protected by mounds of rock. The piling of falsework for the superstructures was similarly cut off. The superstructures themselves were in some instances below the natural banks. The worst effect of such work was not contraction of the channel section, though that was bad enough, but the forming of a barrier to the free movement of drift. Industrial establishments had encroached extensively upon the banks, until, taking all together, the natural channel had been reduced probably one-half. When the flood of 1903 came, every bridge of the 17 in the bottoms, except one, went out. That one, the Missouri Pacific, was weighted with 17 locomotives, and stood, but it led to the formation of a great drift jam which, with the excessive channel encroachment in the vicinity, produced the effect of an immense dam, forcing the water out on both sides and causing

torrential velocities through the bottoms below. The work of a flood could scarcely have been more destructive.

(135) Methods of Relief. This calamity stirred public interest deeply, but not deeply enough, or not deeply long enough, to result in adequate measures. The problem was first formally taken up by a Board of U. S. Engineer officers who considered and reported upon the various plans of relief suggested. Reservoirs on a sufficient scale to control the situation were considered impracticable. A diversion of a part of the flood flow through a tunnel into the Missouri was rejected as impossible on account of cost. Two plans were presented for carrying the flood through the city, one along the existing route, and another by a new route in immediate contact with the north bluffs, thus taking the river practically out of the bottoms. The Board favored the latter plan because of its vast advantages in the development of the West Bottoms, but realizing the difficulties of so radical a step, it specified the necessary improvement to carry the flood along the present channel. This contemplated vertical walls 734 ft apart through the congested section, and levees further up stream; bridges to have only two piers, and these to extend below the scour line; all solid obstructions to be dredged out to 15 ft below the ordinary low water bed, or 45 ft below bank level.

(136) Present Status. The Kansas City problem is the most conspicuous example in the United States of a division of jurisdiction in which two states are concerned. The state line between Missouri and Kansas passes north and south directly across the bottoms a few feet east of the most easterly point reached by the Kaw channel, leaving the entire course of that stream in the State of Kansas and almost the entire course through the bottoms of its troublesome tributary, Turkey Creek, in the State of Missouri. It is doubtless this divided jurisdiction which has prevented the larger municipality from taking the active part in finding a solution of the problem that would naturally be expected. It was left for the Kansas community to undertake the work alone. State legislation was procured and under it a drainage district organized. The general plan of the Board of Engineers above referred to for improving the existing channel was adopted, except that walls

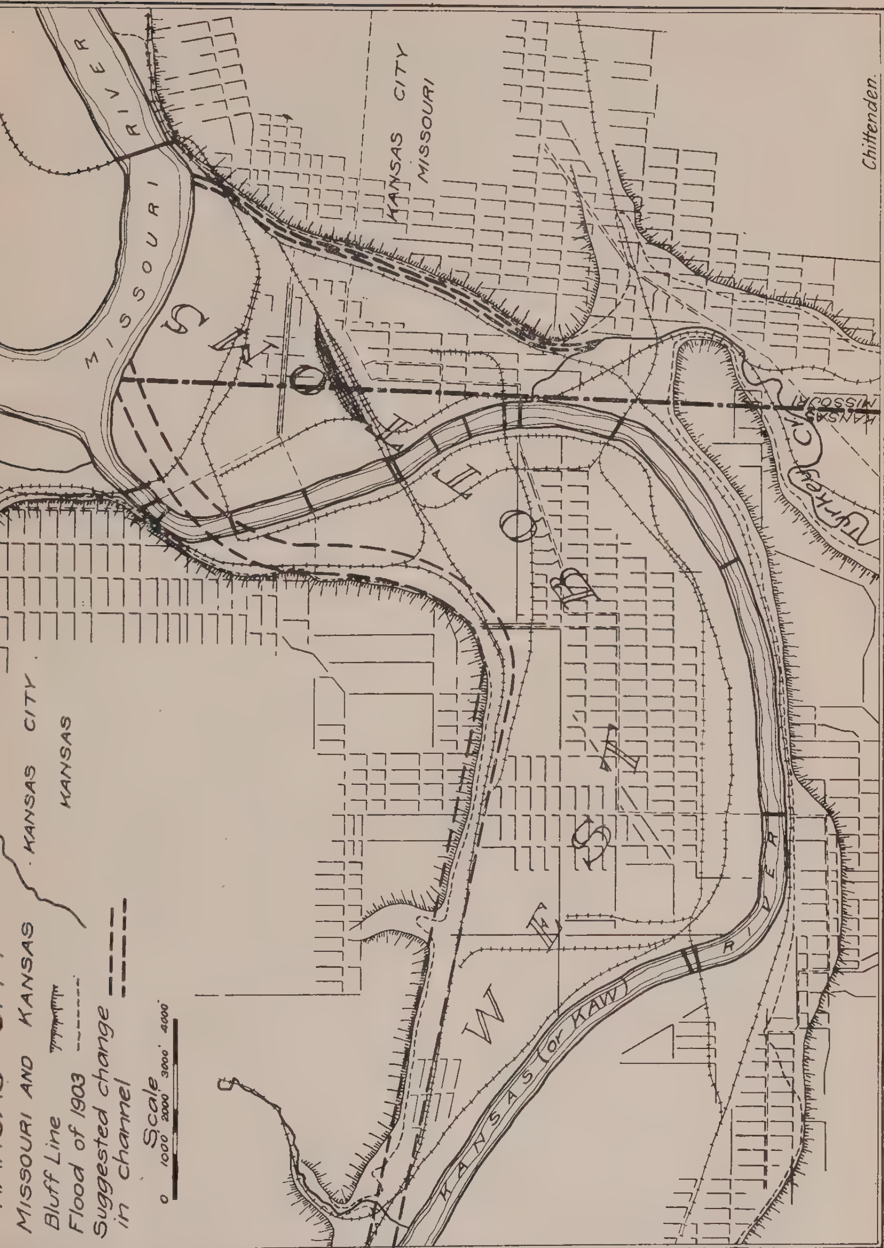

Fig. VIII. Flood-Control Project for Kansas City.

were to be replaced by levees and vertical banks with slopes, the width of channel remaining the same at bankfull stage but the cross-section being reduced by the amount of the side slopes. The recommendations as to bridges are being followed as far as practicable. The wreckage of the 1903 flood still remains in the channel. A considerable portion of the levee system has been built and another flood will find the "bottoms" in far better shape than in 1903 to resist it.

(137) Comment. Kansas City (of both states) "passed up" a great opportunity when it failed, after the flood of 1903, to grapple with this problem in its entirety. For $12,000,000 to $15,000,000, in addition to such federal aid as could be counted on with certainty, the Kaw River might have been practically moved out of the West Bottoms; the enormous handicap of a wide channel twice crossing the bottoms with its many bridges and restriction upon freedom of movement might have been almost wholly eliminated; some 200 acres of ground might have been added where space is becoming so very valuable; Turkey Creek could have been carried along the east bluff and by a tunnel under the railways to an independent outfall into the Missouri; and all the elements of efficient growth of this most important situation could have been immensely strengthened. It is no exaggeration to say that these considerations alone, irrespective of the primary purpose of flood protection, would, in the course of a generation, have returned to this community in increased business efficiency far more than the outlay. Kansas City was twice advised that this was the true course for it to pursue—once by the Board of Engineers of 1903-4, and again in 1908 by an engineer whom it employed to investigate the problem. The very serious obstacle of the State boundary goes far to excuse inaction on the part of the larger municipality, but one cannot help feeling that something of the Los Angeles, Galveston or Dayton spirit of civic enterprise would have found a way to accomplish so great a purpose.

VII. THE LOS ANGELES PROBLEM.

(138) General Statement. This problem is cited because it is the most conspicuous example in the United States of the conditions referred to in Paragraphs 26 and 53 above. Rain-

fall and runoff in the arid regions are erratic and subject to great extremes. Storms are frequently of cloudburst intensity. The steep slopes precipitate the runoff into streams with great rapidity and sudden freshets with short, sharp peaks result. The carrying power of these flood waves is very great and prodigious quantities of debris are brought down the canyons and deposited in "cones" where the flat slopes at the outlets are reached. The deposits are sometimes of great depth and their value as storage reservoirs irrigators have come to appreciate highly. These cones, however, usually work the more or less complete demoralization of the channels, which wander back and forth over the surface according to the caprices of particular floods. Whether the broken up channels are rehabilitated or find their way separately to the sea or other outlet, depends wholly upon local topography. As a rule these conditions are found in sparsely settled sections and are not of serious importance; but when the progress of settlement has developed great property interests where they prevail, it becomes necessary to reduce them to effective control. Such is the case at Los Angeles where a city and an important harbor have grown up in the pathway of these erratic floods, and the problem of their control is being taken up in earnest by that enterprising community. Its details are yet in process of development and only a general outline can now be presented.

(139) Descriptive Data. The San Gabriel River, the principal stream involved in the problem, rises in the Sierra Madre Range which extends east and west parallel with the coast and about 35 mi therefrom. The area of the watershed within the mountains is about 222 sqm. The mountains are lofty, their slopes precipitous and much cut up with canyons, and the rate and quickness of the runoff and its erosive power are high. The stream emerges from the range through a canyon into the coastal plain and at the locality of emergence has built up a cone of some 5500 acres in area. The dispersion of overflow on this cone has led to the formation of two distinct channels, the San Gabriel and the Rio Hondo. The San Gabriel is the easternmost channel and discharges into Alamitos Bay. The Rio Hondo flows nearly parallel with the San Gabriel at an average distance from it of about 2 mi until it enters the

channel of the Los Angeles River, under which name it normally finds its way into Long Beach Harbor, but more recently into the artificial harbor of San Pedro, the port of Los Angeles. The Los Angeles River rises in the mountains northwest of Los Angeles and its course lies directly through the city. The two distributaries of the San Gabriel pass to the westward of the city proper, but the whole territory from the detritus cone to the sea is rapidly becoming absorbed in the growing municipality. The channels below the cone are shallow and unstable, liable to overflow and change. With the increasing extent and value of property in the way of floods and with the newly excavated harbor open to receive their load of silt, the problem is rapidly becoming one of serious importance. The damage wrought by the flood of 1914 outside the harbor was estimated at $7,600,000. Over 4,000,000 cyd of silt was carried into the harbor, rendering some of the slips and channels useless, and shoaling more or less the entire area. The cost of re-dredging is estimated at $400,000.

(140) Rainfall and Runoff. The annual rainfall of this region varies from 10 to 40 in and it is stated that in the past 36 years there have been 18 months in which the rainfall has exceeded 7 in, which generally means torrential floods. The maximum recorded flow at the mouth of the San Gabriel Canyon is 26,680 cfs, or 120 cfsm. Such high stages are of very short duration, but while they last they practically overspread the whole country through which they flow, and are becoming more and more destructive.

(141) Measures of Relief. The problem has not yet been fully worked out but investigations point in certain definite directions. Reservoir storage would be particularly advantageous but adequate sites cannot be found. It is hoped, however, to find storage for about 200 million cf. "Check dams" are proposed along the channels to arrest debris and flatten out the flood wave. The most interesting proposition, though still of uncertain value, is to utilize the detritus cone as a storage reservoir. To accomplish this it will be necessary to spread the flood waters over the cone so as to develop as large a surface of infiltration as possible. It is estimated that an acre of surface will receive from 2 to 6 cfs, but as intimated above,

the practicability of so large a result is not yet demonstrated. A secondary, but very important use of such storage, would be for irrigation. To handle the surplus water which flows over the cone, including that of smaller streams, notably the Los Angeles, the local authorities are planning an elaborate system of regulating works which shall hold the flood waters in fixed

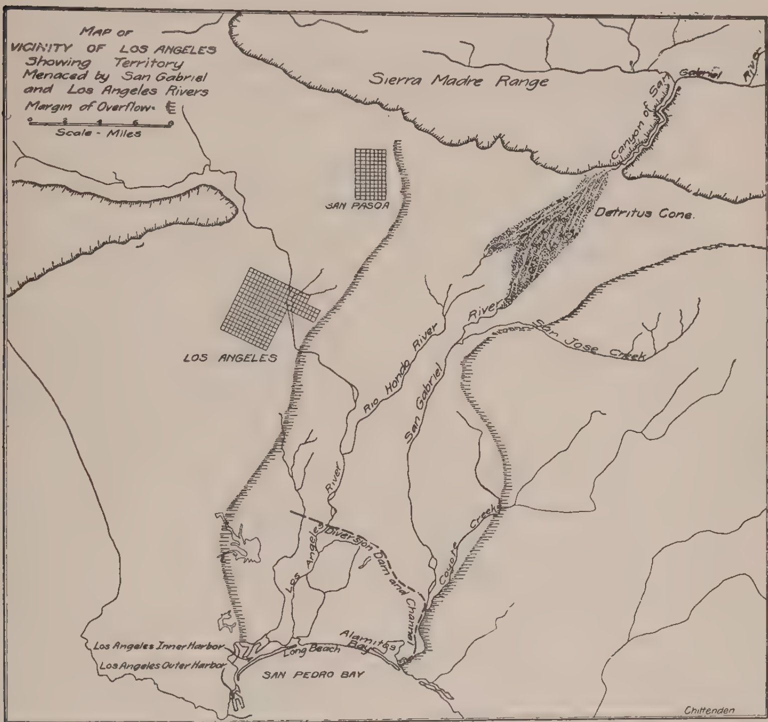

Fig. IX. Flood-Control Project for Los Angeles, California.

channels. The estimated total cost of the project, including some very expensive right of way, is $15,000,000. In addition to this the Government is expected to contribute the cost of a training dike which shall exclude the overflow waters from the harbor and conduct them to an outfall into Alamitos Bay, as shown on the map. The estimated cost of this work is $1,700,000.

(142) Comment. Apart from the unusual physical features which call for special treatment, this undertaking is chiefly of interest as an example of an energetic and determined way of doing things. With almost no natural harbor, Los Angeles is building up a great port, at an expense of some $10,000,000. Without a local adequate water supply, she has gone to the distant mountains and at an expense of $25,000,000 has brought the waters of the high Sierra to her doors. And now that she finds Nature's stream-flow methods inimical to her interests, she does not hesitate to alter them to suit her needs, even if it does cost $15,000,000. This is a spirit of civic enterprise which is worthy of imitation.

VIII. THE DUWAMISH-PUYALLUP PROBLEM.

(143) General Statement. A brief reference is made to this problem because of certain features of especial interest. (a) The streams to which it relates are of a high rate of runoff—torrential in character—and of tremendous transporting power, although they originate in forests of great extent and density and are not caused by cloudburst storms; (b) the problem contains one constructive feature which is believed to be unique in flood control; and (c) two separate jurisdictions (counties), of strongly antagonistic interests, have united under a state law in a joint solution of the problem.

(144) Physical Characteristics. The open valley which forms the great route of land communication between the cities of Seattle and Tacoma was once an arm of Puget Sound and has been filled up by detritus from the Cascades. The valley slopes increase from tide-water on the two sides until they meet on the summit of a cone, over 100 ft above sea level, where White River emerges from the mountains. This stream, in past geologic history, has flowed sometimes down the north side of the cone to Elliot Bay (Seattle), through the Duwamish River, taking in Green and Black Rivers on the way; and sometimes down the south side to Commencement Bay (Tacoma) through the Puyallup River which it joins near the town of Sumner. The watershed of this central stream is about 480 sqm in area and its rate of maximum runoff, though never accurately measured, no doubt reaches 100 cfsm. Its contribu-

tion to the floods of the side on which it has flowed has always been sufficient to determine their destructive character.

(145) Method of Relief. For many years prior to 1906 White River had been flowing mainly north down the Duwamish, though there had been continually recurring strife between the two sides (King County in which Seattle is located and Pierce County in which is the city of Tacoma) to compel it to flow as either contestant desired. In November, 1906, an unusually heavy freshet carried the river over bodily into the Puyallup and carved out so deep a channel that it seemed likely to remain there. This flood was so great a disaster to the valley that the question of future control was taken up in earnest. A Board of Engineers made a full investigation and submitted a definite program which, in its main features, is now being carried out. The route via the Puyallup to the sea being much the shorter, the Board recommended that the White River be held there. But as this would throw all the disadvantages upon Pierce County and give to King County all the advantages, it was recommended that King County bear the major portion of the expense. After years of controversy, with some litigation, and action by the State legislature, a compromise was effected on the lines of the Board's recommendations. The cost is estimated at $1,500,000, King County to provide 60 per cent and Pierce County 40 per cent. The work includes a massive concrete dike to hold White River permanently on the south slope; extensive channel rectification from the diversion dike to the bay; and the device to be described in the next paragraph.

(146) Drift Barrier. The quantity of drift wood—logs, uprooted trees, brush of every description—that is carried by such a stream as White River, is enormous and sufficient to render nugatory any efforts at flood control. Relief from this drift was an absolute prerequisite to the physical solution of the problem. To trim off the trees which were liable to fall into the stream and to keep logs and debris from getting in was too big a proposition to be entertained. It was therefore decided to erect a barrier below the main sources of drift with a view to developing an artificial drift jam which should effectually arrest all debris from above. The type of structure

adopted consists of a line of 27 concrete piers spaced at 64 ft centers across a contracted section of the valley. Each pier rests on a pedestal 3 ft thick, diamond shape in plan with the diagonal dimensions 27 and 30 ft. respectively. The piers are truncated sections of pyramids, 13 ft high above the pedestal, the top surface sloping toward the current. Connecting the piers is a series of 10 steel rods of 1½ in diameter, braced at frequent intervals with angle bars, the whole giving the appearance of a powerful fence standing about 11 ft high above the level of the pedestals. The line of rods is continuous through the piers and the whole fence slopes down stream at an angle of about 20 degrees with the vertical. It is expected that the accumulation started by this barrier will soon become massive enough to sustain itself, and that the flood waters, in passing over and through it, will virtually be strained of whatever debris they are carrying.

IX. THE COLORADO PROBLEM.

(147) General Statement. Unique among the flood problems of the globe is that of the Colorado River between Yuma and the sea. It is unique in the physical features involved; unique in the jeopardy in which a potential empire is placed by its possible failure; unique in its jurisdictional complications and in the anarchic conditions under which operations have been carried on; and unique in the heroic struggle against stupendous odds which has given an almost romantic glamour to its record during the past decade. In briefest statement the physical problem is to prevent a river, which is the sole possible reclaiming agency of a vast tract of rich agricultural territory, from becoming its ruthless destroyer. How this tremendous conflict of purpose can exist will appear as the subject is developed.

(148) The Colorado River. The Colorado River rises a little south of the Yellowstone Park, flows south through 12 degrees of latitude, draining the western slopes of the Continental Divide all the way and empties into the Gulf of California. It is essentially a mountain stream in the upper half of its course, and what we may call a desert stream in the lower half. The mountain supply is fairly uniform in its annual

habit, rising with the melting snows with great regularity. The desert sources are erratic and subject to great extremes. This is particularly true of the eastern tributary, the Gila, which drains the southern half of the state of Arizona and a large section of western New Mexico. This stream, which plays an important part in the Colorado flood problem, joins the main stream at Yuma, the head of the delta. The areas of the watersheds above Yuma are:

The Colorado above the Gila	198,000	sqm
The Gila	64,500	"
Total	262,500	"

(149) So varied are the climatic conditions on the watershed that a statement of mean annual or monthly precipitation would afford no indication of results in runoff. From the mountains comes a fairly uniform variation of discharge with the seasons, but in the southern watersheds the habit of the streams is subject to very little regularity. The term "flashy" is perhaps the best descriptive one that can be found. The Gila, for example, with all its vast watershed, frequently goes dry at Yuma. and again in a few hours it may become a raging torrent of 100,000 cfs or more, bearing along prodigious loads of earth and driftwood. The maximum discharges of the main stream at Yuma and of each tributary just above are:*

The Colorado at Yuma 150,000 cfs (probably more) or 0.57 cfsm.

The Colorado above the Gila 145,000 cfs (probably more) or 0.73 cfsm.

The Gila 100,000 cfs (probably more) or 1.54 cfsm.

The above flood rate for the whole watershed is probably the lowest on record for any important stream in the United States. The most important flood characteristics of the lower river are (a) the gradual annual rise and fall in June from the upper Colorado; (b) the "flashy" rises from the Gila and

* Discharge data unsatisfactory from point of view of flood study Yuma record does not sufficiently disclose origin of floods and freshets. Simultaneous observations on main stream at Yuma and points above and on every important tributary would give a better basis for conclusions, particularly as to the practicability of reservoir control.

lower Colorado; (c) and the enormous quantity of sediment carried, amounting to an annual average of 53 sqmf or 54,-725,000 cyd (41,826,000 cM).† It is this last characteristic that determines the nature of the Colorado flood problem.

(150) Imperial Valley. In not remote geologic time the Gulf of California extended northwesterly some 200 miles beyond its present limits—far into what is now the State of California. The outlet of the Colorado was in the vicinity of Yuma. The constant deposition of sediment from the river, which may formerly have been even greater than now, eventually built a dam entirely across the Gulf from Yuma to the Cocopas Hills, and gradually raised it to a height of nearly 40 feet above tidewater. During this process the river spilled alternately over to one side and to the other. When flowing over the west slope, the cutoff portion became a freshwater lake, the beach line of which is distinctly traceable. Whenever the river flowed down the Gulf side for long periods, evaporation emptied the lake and this has clearly been the situation for some centuries past. In the bottom of the basin there seems always to have remained a small quantity of water and to this the name "Salton Sink" attached, becoming later "Salton Sea" when it expanded into a large body of water. That portion of the basin lying northwest of the Sink is called the Coachella Valley and is all in California. That portion to the southeast is called the Imperial Valley and lies partly in Mexico. This name is gaining ascendency in popular use. The bottom of Salton Sink is about 280 ft below sea level. On the broad flat divide between the Gulf and the Imperial Valley is a shallow pond of considerable extent called Volcano Lake with originally an ill-defined outlet (New River) to the north, and a well-defined outlet (Hardy's Colorado) to the south. The total area of the Salton Basin below the old fresh water beach line is about 2100 sqm.

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† See Water Supply Paper 251, p. 39; House Doc. 504, 62nd Congress 2nd Sess. ("Physical Facts"), p. 162; Trans. Am. Soc. C. E., vol. 59, p. 10 (Colo. R. and Salton Basin, by C. E. Grunsky). This indeed seems to have been the accepted figure, but Bulletin 44, Arizona Experiment Station, gives over 3 times this figure (164 sqmf) for the year 1900, while observations of the Reclamation Service for 4 years and 9 months (1909-1913) give 8 times this figure (426 sqmf).

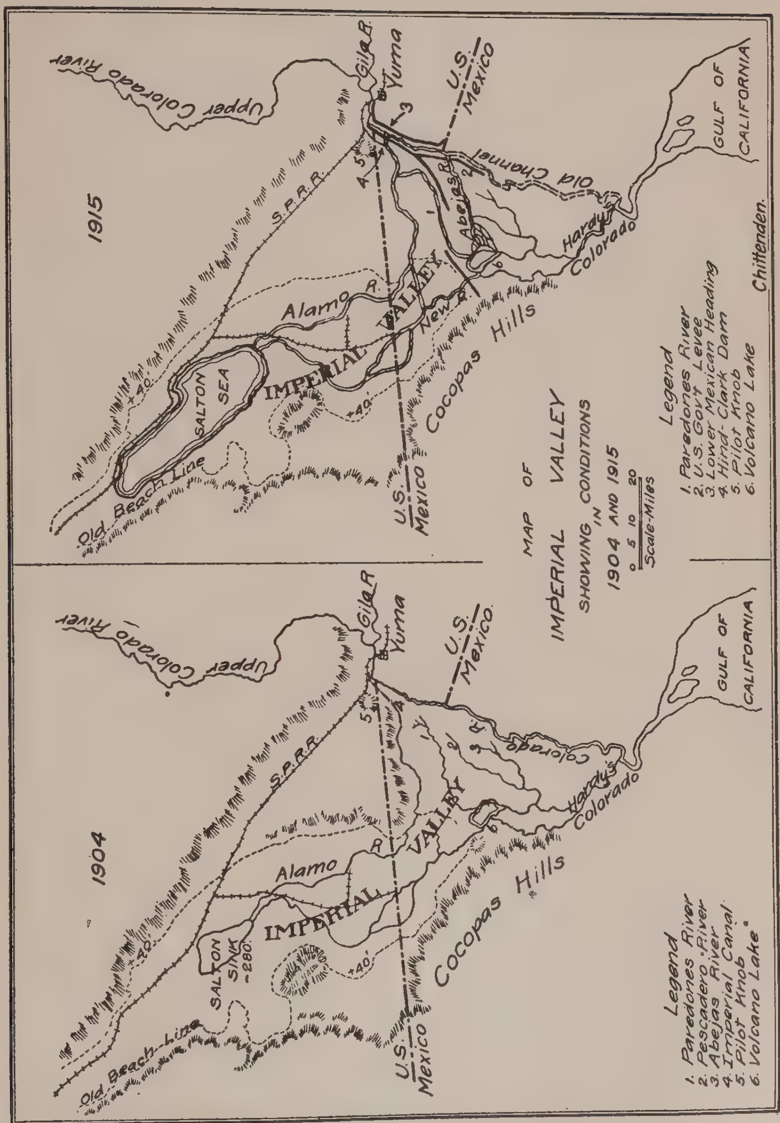

Fig. X. Imperial Valley and the Colorado River Delta.

(151) Dependence on River. For nearly half a century this region was known as the Colorado desert and was believed to be uninhabitable on account of heat and untillable on account of alkalinity. Both of these theories have proven fallacious. The land is exceedingly fertile and perfectly adapted topographically to irrigation. When the actual condition came to be realized, occupation of the valley began and has increased with unexpected rapidity. No white man lived there in 1900. The estimated population in 1910 was 15,000 and the value of property at the present date about $40,000,000. The rainfall in the valley amounts to only 2 to 3 in annually and is of no reliance for agricultural operations. For these, there is only one source, though an ample one, the Colorado River which flows along the eastern rim of the basin. The vital function of this stream in the industrial development of the valley may be judged from the fact that, without rain, without ground water or any other independent supply, vegetation would wither, stock perish of thirst, and the whole region quickly relapse to desert conditions, if this single supply were cut off for even a short period.

(152) The Delta. From Yuma to the sea the air line distance is about 60 mi. The channel distance before 1905 was about 80 mi and the low water slope nearly 1.6 ft per mi. The channel varied greatly in width, ranging from 500 to 1000 ft at low water and from 800 to 3000 ft at high water. It was a shallow, ill-defined and unstable channel, and always overflowed in high water. The crest of the ridge on which the river, until 1905, had been flowing for an unknown period, lies near the eastern mesa, except for a short distance below Yuma, and the overflow has been mainly on the right bank. The rapid process of up-building has resulted in unusually unstable equilibrium, even for deltaic rivers, but the tendency to break out has been largely counteracted by the extremely dense tropical growths which follow the natural irrigation of the river. Some distance back from the banks the overflow gradually gathered into defined channels which led away to the west and southwest, some of them like the Alamo and New Rivers, draining into Salton Sink, and some of them like the Pescadero, Peredones and Abejas, into Volcano Lake and thence mainly back into the Colorado, though partly at times in the other direc-

tion. It is generally agreed that the course of events pointed to an early shifting of the river to a western outfall, and that its tendency in this direction only awaited a favorable opportunity. This came quite unexpectedly and unwittingly through the agency of man.

(153) The Break. So well had nature protected the banks from any irruption of the river that, when man undertook to draw from it the small amount he needed for the new irrigation enterprises in the Imperial Valley, he found no little difficulty in coaxing the water in that direction. His first channels silted up as fast as he built them, and so little seemed the danger of any excessive flow that later he omitted the precaution of controlling gates altogether. But finally he went a step too far, overreached the balance of forces, and the water started to flow with a volume that kept its sediment from depositing. From that it was but a step to the point where it would carry more than its own load. It began to load up from its own channel. The channel section grew apace. The managers of the scheme became anxious. Crude methods of introducing control were ineffectual. Effort after effort to stem the current failed. A series of unprecedented floods intervened, and things went from bad to worse until the entire river was flowing west and the old channel to the sea became dry. Water began to rise in the bottom of the valley and Salton "Sea" became a growing reality. The salt works located there were destroyed, and the Southern Pacific had to move its tracks to higher ground. The Alamo and New Rivers began cutting back their channels, forming great barancas or chasms, in some places a quarter of a mile wide and 40 to 60 ft deep. This resulted in cutting off some of the irrigation canals and menacing others until the whole unprecedented situation threatened the valley, first with fatal drought, and later with a deluge as complete as that of Noah. The rate of progress of this back-cutting made it probable that it would extend to Yuma and beyond, destroying the Government reclamation works there and all uses of the river in its present condition.

(154) The Closure. The headgate of the canal was first located on American soil, but the topography compelled leading the canal southerly a considerable distance into Mexican

territory before it could be swung off to the westward in the desired direction. It was at this bend, after failure to keep the upper channel open, that a cut was made 3300 ft long directly east into the main river. This was the so-called lower Mexican heading. The difficulty so far experienced in making the canal carry water at all, and the extreme urgency of haste to meet the necessities of settlers in the valley, led to the opening of the canal without any controlling works, and thus to the disaster just related. When the gravity of the situation began to dawn upon those responsible for it, strenuous efforts were made to avert the impending disaster. Numerous abortive attempts were made to divert the river away from the heading, and then to close off the channel itself. Owing to the financial collapse of the irrigation companies concerned, the Southern Pacific was forced to assume direction of affairs and most of the work until closure was effected was done under its direction and with its funds. Among the several attempts, before final success, may be mentioned the construction of a bi-pass with a large timber headgate before actual closure was attempted. The bi-pass channel when ready was opened to the flow, and the damming off of the main channel was begun. This had scarcely been accomplished when the headgate itself rose and floated away. A mattress and rock dam was then constructed, prolonged by levees at the two ends. This seemed to have accomplished its purpose when a sudden freshet from the Gila a month later undercut the levee on the south side and flanked the dam completely. In sheer desperation, the engineers then resolved on the bold expedient of building a rock dam across a torrential river flowing in a bed of pure alluvium, and this, contrary to all engineering advice, without a mattress of any sort. Only the gravity of the case led to this expedient, which astonished everyone by its complete success. Two parallel lines of trestles were built and mounds or ridges of rock simultaneously deposited. The whole resources of the Southern Pacific in the production of rock were called into play within a radius of 400 mi. The channel was 1000 ft wide; the mid-depth of water about 34 ft; the volume of flow 20,000 to 40,000 cfs. The break was closed in 15 days by dumping in an average of 5000 cyd per day. The dam was further strengthened until it contained

about 200,000 cyd, of which about half was rock. It was an expensive operation, but the future of a small sized empire was at stake and the end justified the extraordinary means employed. The second closure was effected in February, 1907. The first dam across the break was called, from the field engineer in charge, the Hind dam, the second the Clarke dam, and the consolidated structure the Hind-Clarke dam. This last work, it should be said, was done by the railroad company under promise of reimbursement in part by the interests of the valley, and at the urgent insistence of President Roosevelt. The company, with the prospect before it of having to shoulder the whole burden, had decided to quit, but was induced to hold on in the expectation that Congress would assume at least part of the cost. This it was urged to do by the President in a special message, but nothing has yet been done.

(155) The Abejas Diversion. The break in the river bank had led to deterioration of the old channel and when the river was turned back into it, the annual flood of 1907 caused more overflow than usual and this was accentuated in 1908 and particularly in the high flood of 1909, resulting in the diversion of the entire river through an overflow channel, the Abejas, into the Pescadero and thence into Volcano Lake. The prospect that something of this kind would happen had led to the construction of a levee north of Volcano Lake to prevent its overflow from getting into Imperial Valley. This has been measurably successful, though the steady filling up of the lake and the consequent rise of flood stages increases danger of failure. The situation growing more threatening, Congress was at last aroused to action, and in June, 1910, appropriated $1,000,000 toward the work of control. It was decided to use this in closing the Abejas break, leveeing the channel above and below, thus attempting to restore the river to its old course. The work was done in 1911, but with the annual rise of that year, a considerable portion of it was destroyed and the river returned to the Abejas channel. This left matters as bad as before. The river is now flowing into Volcano Lake whence it finds its way mainly south to the Gulf. A levee extending from the old closure (Hind-Clarke) southwest for a considerable distance helps to keep overflow out of the valley, but there is at this

writing a gap between this and the Volcano Lake levee, while the latter is not strong enough for the duty required of it. The situation is precarious. The river is building up its new channel, adjusting its slopes, and must inevitably encroach to the westward and crowd the present works beyond their capacity. A new crisis in the situation may be expected at any moment, and Congress has again been asked for relief.

(156) Future of the Problem. In the present critical situation, it is not wise to attempt any forecast. But it may be said that, for any adequate solution of the problem, the Imperial Valley must be, in the words of General Marshall, "forever divorced or separated from the Colorado delta proper". There is agreement on this point, but disagreement as to whether the line of divorcement should be that of the banks of the old river channel, or along the line of the present channel and the Volcano Lake levee. If the first line be not physically impracticable, it would, in the opinion of some engineers, be better, as being much shorter and giving a greater area of protection. In the rapid upbuilding of the river banks on the present route, the same physical problem, they contend, must soon be met there as on the other. To restore the old route will be indeed a herculean task, but possibly no greater in the long run than to hold the other line, and it is urged that it might as well be grappled with at the outset.

(157) Reservoirs. Some help may be expected from reservoirs, but not enough to lessen in any marked degree the special work required on the delta. The mountain reservoirs will be more than a thousand miles away. They would tone down to some extent the June rise, but would have no effect on the flashy freshets from the lower rivers which are a source of so much trouble. For the control of these, other reservoirs will be necessary and their availability is affected by the question of silt. All practicable storage will be justified as an irrigation measure and will be of some advantage in controlling floods; but it is not likely that the delta problem can be solved by their use.

(158) The International Boundary. A vexatious feature of the problem has been from the first the fact that an international boundary divides the territory in question. Such

divided jurisdiction would be in any case a handicap, involving as it must, mutual arrangements and treaties and a joint commission for executing the work. But this is nothing to the actual situation, where constituted authority has disappeared and the theatre of operations has fallen a prey to anarchic control, with its jeopardy to life and property, its interference with operations and its onerous pecuniary exactions. The government work of 1911 suffered severely from this cause. It may be accepted at once that, whatever solution of the physical problem is ultimately determined upon, there can be no permanent result until mutual cooperation of the fullest character is agreed upon between the two governments. And such an agreement can not be indefinitely delayed, for we are dealing with forces that know nothing of national jurisdictions and will not stand aside to suit international convenience. Authority to act must in some form be created without much further delay.

(159) Comment. In the midst of so much apparent misfortune, so great an expenditure without definite result, and the continued danger of a hopeless catastrophe, the course of events may nevertheless prove to be the most fortunate that could have happened. If, as is generally conceded, the limit of equilibrium of the river had been almost reached, and if it was bound in the near future to go back to the Salton Sink, it is fortunate that the event was precipitated at the beginning of development of the valley rather than after that development had been far advanced. The problem has confounded our best engineers. It has required hard knocks to show what has to be done. The money spent has not been wasted. It has equipped the profession with the necessary knowledge to handle the problem from this time on successfully. Only failure of the two governments to act with promptness and vigor can prevent this.

And the apparent destruction which has been wrought is not without its benefits. The great barancas supply a drainage system absolutely necessary to the successful development of the valley, and the 400,000,000 cubic yards excavated from them has raised the bottom of a large area of Salton Sea where it will all be available for use. The filling up of Volcano Lake

which is going on will hasten the time when its area also may be turned to account. If once the unruly river can be reduced to control, the seeming misfortunes of the present will yet be looked back upon as the real groundwork of the making of the valley.

X. THE RAILROAD PROBLEM.

(160) General Statement. There is no other interest so directly concerned in the flood problem as that of the railroads. They lie along or across nearly all of the streams of the country. Their yards are frequently in low bottoms subject to overflow. Scarcely a considerable flood can occur in the more thickly settled portions of the country that does not affect them. Destruction of roadbed and rolling stock are but a portion of the losses suffered. More serious, though more indefinite, is the loss from demoralization of traffic. Railway policy in dealing with the problem is therefore of public interest, and a list of questions on the subject was submitted to the chief engineers of the principal systems of the country. Their answers, which were gratifyingly complete, are summarized below.

(161) Bridges and Culverts. *Question.* What is your rule for computing flowage space under your bridges or through culverts?

In nearly all cases Talbot's formula is used, namely, $O = CA^{3/4}$, in which O is the desired opening in square feet, A the area in acres, and C a coefficient varying from $\frac{1}{6}$ to 1 according to the slope, character and condition of the watershed. In one state, Pennsylvania, a special formula giving a larger flowage space is required by the Water Supply Commission and railroads have to conform to it. In most cases, engineers endeavor to supplement the formula result with such data as to actual flood heights as can be obtained. With larger structures than culverts and very small bridges the general practice is well expressed by the Chief Engineer of the Pennsylvania system: "Length of spans of large bridges is based on experience, character of foundation, depth of stream, current velocity, tendency to scour, direction of current and economic cost".

(162) Policy as to Extraordinary Floods. *Question.* In case of extraordinary floods, freshets, from waterspouts, etc., is it your policy to make complete future provision against recurrence of such disasters, or do you consider it better to provide against average or even great floods only, accepting the consequences of the extraordinary floods rather than go to the great expense of making full provision against them?

The answers to this question were uniformly to the effect that complete protection against extraordinary events of rare occurrence is not undertaken when the cost is very great. Everything depends upon circumstances, and the effort is always made to balance possible damages against cost of protection so as to determine the line of true economy. As a rule this results in a decision to take chances with extraordinary visitations.

(163) Serious Features of the Problem. *Question.* What are the most serious and frequent features of the flood problem on your lines?

As would naturally be expected, the answers to this question were controlled by the locality. In the north, ice gorges are a fruitful source of trouble, as are log jams in densely forested regions. Insufficient capacity of culverts, undercutting of tracks along river banks, breakage of levees along streams subject to high overflow, improper diversion of natural water courses, neglect of obvious precautions in protecting properties, submergence of low yards, as at Pittsburg and Louisville, etc. In the mountainous regions of the west, cloud bursts producing sudden freshets of great violence are an ever present menace and are well-nigh impossible to guard against. The crossings of detritus cones at the outlets of canyons are particularly vulnerable points. The shifting of the channels over the surfaces of these cones is very difficult to control, and frequent moving of tracks, or new diversions of the channels become necessary. In some situations overflow is anticipated and embankments are thoroughly revetted so that it may take place without further harm than temporary interruption of traffic. As a general rule, the flood problem becomes less serious with the age of a road, for developments are met as far as possible as they arise and the capacity to resist floods becomes at last nearly perfect. But

no practicable measures will ever entirely avert such catastrophes as that of the flood of 1913 in Ohio and Indiana.

(164) Flood Service. *Question.* Do you have any organization for dealing directly with flood problems on your lines, or for warnings and observation in times of danger?

Very few roads have done much in this line. The Missouri Pacific seems to have gone farther in this direction than any other system. It employs a drainage engineer whose duty it is to deal with all problems of this character. Other systems like the Illinois Central, which operates so extensively in the flood plain of the Mississippi, have specially prepared diagrams and data, derived from previous experience, which are put into use in time of flood. Some of the expedients resorted to in great overflows are extremely ingenious and interesting. As stated in the previous section, the development of lines and the better control of rivers, are gradually lessening the necessity of special organizations for dealing with flood problems.

(165) Railroad Losses. *Question.* Have you a record of flood losses on your lines in recent years?

Only a few answers contained definite information. It is in fact a difficult subject to deal with in a satisfactory way. Direct losses may be measured in the cost of rehabilitation, but indirect losses are more or less guesses. The floods of 1912 and 1913 caused a direct outlay to the Illinois Central of nearly $2,000,000. The 1913 flood loss to the Baltimore and Ohio is given as $2,500,000; that of the Pennsylvania system at $3,600,-000. The flood losses of the Missouri Pacific for 8 years are given at $1,600,000. The flood losses of the Oregon-Washington R. R. and Navigation Company, a mountain system mainly, amount to about $875,000 for the period 1906-14.

(166) Public Policy. *Question.* Have you given any thought as to what public policy, if any, should be adopted to avert or lessen disasters from floods?

On this question, so far as it was considered, the opinion seemed to be that on the great rivers like the Mississippi, public authority should provide protection from overflow; but otherwise the railroads can better deal with the problem themselves, so far as it affects them directly.

DISCUSSION

Col. C. McD. Townsend,* M. Am. Soc. C. E., states that the necessity of flood control has been impressed upon the people of the United States by the disasters of the last few years, particularly by the floods of 1912 and 1913 in the valleys of the Ohio and Mississippi Rivers, and that numerous advocates have arisen of particular systems of flood protection which alone, in their judgment, can solve the problem. General Chittenden has performed a public service in calling attention to the fact that no system is applicable to all streams, and that to obtain proper results each case requires careful individual study and the utilization of great engineering skill. While the author has discussed the flood problem very exhaustively, it is the writer's opinion that a further analysis of the flow of sediment in a river, and the effect it has on the river section, will enable one to differentiate more accurately which of the various methods of flood control best can be employed. Col. Townsend.

The movement of water from its deposition on the land as rain or snow to its return into the sea is accompanied by a degradation of the hills and a filling-in of the valleys. At the headwaters of most streams there is an inverted conical surface on which the earth's crust is being eroded. On the gentle slopes of a rolling prairie the rain-water moves principally sand and the finer sediment which is carried by the waters in suspension, but in mountainous countries, aided by frost and other atmospheric agencies, the water is capable of moving large boulders.

Just below the cone of erosion, there is a section of the stream where the eroded material is transported without deposition. Mountain torrents whose slopes exceed 10 feet to the mile are capable of transporting long distances the large detached boulders. Such torrents also are erosive in their action and under certain conditions excavate the canyons found in some of our western States.

But on such watercourses the slopes tend to diminish as the streams approach the sea, and usually at a relatively short distance from the stream source the velocity diminishes so that deposition begins to take place. At the upper end of the valley of deposition the boulders are deposited, next the smaller stones, then the gravel, and finally the sand. These materials are rolled along the bed of the stream and in addition there are carried in suspension finer particles, some of which are transported by the current to the mouths of the rivers and form the deltas which are encroaching constantly on the ocean bed.

When material is once deposited, it requires, to again set it in motion, at least as great a force as that which originally transported it; hence, the boulders deposited are moved only during extreme floods, while the sand is moved at moderate stages. The progress of all the material rolled along the river-bed is intermittent, however, and relatively slow. The movement of the sand-wave created by hydraulic

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Col. Townsend.

mining in the Sacramento Valley has been estimated at about 4 miles per year; and in the upper Mississippi River movement of sand-waves does not exceed 2500 feet per year.

Wherever the heavier material is deposited, the location of the low-water channel is erratic and is liable to change with every flood. When lighter materials happen to be deposited among the heavier, the stream-bed is scoured out. Its pools are as liable to be in the straight reaches as in the bends, and the local stream-slope is dependent upon the material encountered; but among the lighter gravels and sands the current exerts a scouring action for long periods and the channel attains greater stability. Here the pools are formed in the bends and are separated from each other by sand-bars in the connecting reaches. Where this condition occurs, the sediment carried in suspension begins to be deposited; and whenever the sediment is moving with the same velocity as the current, deposition occurs if the current be checked suddenly. As the discharge of the stream increases during floods, the channel previously excavated in the sands is incapable of containing the floods and they overflow the valley. The overflow water moves with less velocity than the water in the main channel and tends to deposit its sediment close to the main channel where the velocity is first checked, and thus forms a ridge which rapidly enlarges the channel capacity. The alluvium thus deposited is readily eroded by any increase in velocity or any change in the direction of the river currents.

The characteristics of the alluvial valley thus formed differ markedly from those of the valley up-stream. The cross-sections of the alluvial valley slope downward away from the river instead of toward it, and the rain falling on the surface, instead of flowing directly to the river, flows first toward the bordering hills of the valley, at the foot of which it forms auxiliary channels flowing sometimes for long distances approximately parallel to the main stream before they break through the ridge forming its bank.

In an alluvial valley, the river intermittently moves along its bed large quantities of sand and gravel, which toward its mouth become finer due to attrition. Also during floods the stream carries a large amount of material in suspension which is deposited with any sudden diminution of velocity; and the river banks are easily eroded. Such a stream constantly is striving to adjust its bed to its discharge and slope. As the discharge increases, the pools tend to deepen and the crossings to widen; and as the discharge diminishes, a reverse action takes place. On steep slopes there is a tendency to scour out deep bends in the river banks and thereafter exhaust a large amount of the energy created by the slope in overcoming the resistance of the bends, as pointed out by M. Engel in his article on "Navigability of Rivers", Vol. 29, Trans. of Am. Soc. of Civil Engineers. As the slope diminishes, the streams tend to move in gentler curves.

On many streams, however, alluvial valleys do not exist. In pre-

historic times a large portion of the United States was covered with a heavy layer of snow and ice and many valleys were formed by glacial action. Col. Townsend.

The deposition of material eroded by glaciers is governed by laws entirely different from those applying to flowing water. Detritus once enclosed in ice is transported without regard to the velocity of flow, until the ice melts. Hence glacial drift is not assorted as to sizes of materials, as are deposits in flowing water; but boulders, stones, sand and gravel are carried to the foot of the glacial valley, and there deposited in a confused mass which it is difficult for water to erode.

Glacial valleys, therefore, are usually of gentle slope and are liable to contain extensive lakes and marshes. After a glacier has disappeared, the material eroded by rain from the bordering hills is deposited in these lakes or marshes; and as the banks of the stream are composed of stiff materials not readily eroded by the currents generated by the gentle slope, the stream carries but little sediment and its banks are quite stable. A large river like the Mississippi has numerous tributaries, some of which rise in glacial valleys while others are alluvial in their nature. In some branches the cone of degradation extends to the main stream, while the valleys of others are filled with alluvial deposits for long distances above their mouths; and as a result, the amount of sediment carried by such a river is variable, and depends not only on the stage of the river but on the part of the country in which the flood arises. Nevertheless, on the lower courses of most rivers a general equilibrium has been established; and while there may be great local disturbances the amount of sediment which flows into the river equals that which is discharged from it, as is shown by the fact that in most rivers there has been no appreciable raising or lowering of the river bed since river records have been preserved.

Such alluvial valleys are being encroached upon by sand-waves at their upper ends and their deltas gradually lengthened; but the resultant changes in slopes are created very slowly. When the problem of flood control consists in preventing erosion of gentle prairie slopes, a grass sod or even plowing in furrows at right angles to the flow will afford a sufficient remedy. On steeper slopes the erosion can be prevented only by stronger vegetable growths, such as shrubs or trees, or by terracing the sides of the valley; but the slopes may become so steep that any vegetable covering merely adds to the material which is washed into the valley during extreme floods.

If the problem consists in preventing detritus from covering arable lands at the head of the valley of deposition, the only practicable method consists in causing the deposits of the detritus in the valley of transportation by dams, as the tailings from hydraulic mining were confined on the branches of the Sacramento River; or by drift barriers as proposed in the Duwamish-Puyallup problem described by the author; as such depositories fill, others must be constructed.

Col. Townsend.

At the heads of the valleys of deposition, the simplest method of controlling flood waters is by reservoirs or detention dykes. If reliance be placed on levees in such localities, the space between them rapidly fills with boulders and stones; and as the bed of the stream is raised the levees have to be increased in height to compensate for this fill, or the fill removed annually. Around Lake Biwa, in Japan, Colonel Townsend observed several leveed streams whose beds appeared to the eye to be more than 10 feet higher than the surrounding country. Near large towns where stone has a commercial value for road construction and repair, the removal of the detritus annually may afford the most satisfactory solution of the problem.

The author has called attention to the diminution in the influence of reservoirs on flood control as the distance from the reservoir increases, due to the reservoir capacity of the river itself. This is shown forcibly on the upper Mississippi River. At its headwaters six reservoirs have been constructed with a combined area at high water of 490 square miles, in a watershed of 4535 square miles. The hydrographs of the river at St. Paul compared with those at Reads Landing at the foot of Lake Pepin (76 miles below St. Paul) show clearly how much more efficient in regulating flood-heights is a natural reservoir of less than 40 square miles area in the bed of a river, than artificial reservoirs of much greater capacity located at its headwaters—the range between high and low waters at St. Paul being 18 feet, while at Reads Landing it is only about 12 feet. In fact, below Lake Pepin it is impossible to detect any effect from the artificial reservoirs on the river discharge, either at high or low water. Again, the Mississippi River for a distance of 1000 miles below Cairo has an average width between levees exceeding that of Lake Pepin, so that its reservoir capacity, even without overflowing its basins, is enormous; but like all reservoirs, its effect may be negative if it has been filled by previous rains on the watersheds of the lower rivers.

In a glacial valley whose streams carry little sediment and have not sufficient velocity to scour their beds, even during floods, the channels may be deepened and straightened and additional channels and outlets constructed without serious consequence; but in an alluvial valley, the greatest care must be exercised in using any of these agencies. In the outlets from the Great Lakes, straight channels have been excavated from 300 to 600 feet in width and of depth exceeding 21 feet at low water. These channels are permanent, though changes of slope have occurred, but in the Mississippi River the 9-ft. channel dredged through bars fills annually.

Such deposits on bars have a peculiarity that merits attention, however: even when derived from material in suspension they become compacted on deposition, and if again put in motion, only a small portion is carried in suspension, the great mass being rolled slowly along the river bed. Time is an important element in the problem of enlarging a river channel to pass a flood, and if reliance be placed on widening and

deepening the bed of an alluvial stream there is danger that during low stages fills will occur which a flood will be unable to remove before its crest passes. A sewer which has been partially filled with deposits can be cleaned by gradually increasing its discharge, but a sudden flood may clog it completely. Col. Townsend.

The straightening and shortening of an alluvial stream by cut-offs introduces serious complications. While at first the slope is greatly increased through the cut-off over that which previously existed around the bend, this is but a temporary condition. The energy which had been expended in overcoming the friction of the bend and that resulting from a steeper slope, is expended in largely increasing the velocity. This increased velocity produces a scour and a deepening of the river-bed above the cut-off and the eroded material is deposited on the gentler slope below, raising the bed; and this action continues until the slope through the cut-off is less than formerly existed around the bend. The influence of this extends for long distances above and below the cut-off, and a long period is required before the river again comes to an equilibrium; and even then it will be found that though usually a good channel with a gentle slope exists through the cut-off, the slopes and the low-water navigation have been seriously affected for several miles above and below it. It is this raising of the river-bed below cut-offs and the injurious effect on navigation above and below them, which causes De Mas and other French writers to caution against their use—and they cite, as an example, the changes caused by straightening the Canal de Miribel on the Rhone.

The action of cut-offs on the Mississippi River has been similar. The Kaskaskia cut-off, about 69 miles below St. Louis, which occurred in 1881, has a length of 7½ miles and shortened the River about six miles. The average slope of the Mississippi River in this locality before the cut-off occurred was about 0.6 foot per mile. The present slope through this cut-off is 0.23 foot per mile. Its channel causes no trouble to navigation, but dredging has been required annually a few miles above and below it to maintain 8-ft. depths.

The Waterproof cut-off, which occurred May 10, 1884, is the only one which has been permitted on the lower river since the creation of the Mississippi River Commission. Originally it was about ½ mile long and shortened the river about 12 miles. The survey of the Mississippi River in 1883 indicates a low-water slope around the bend of 0.22 foot per mile. A survey made fifteen days after the cut-off occurred gives a slope through it of 0.81 foot per mile; and in October, 1884, the low-water slope had become 0.33 foot per mile, and in 1889, 0.146 foot per mile. The survey of 1913, though made when the river was rising three feet per day, gives a slope of 0.34 foot per mile. At various times the following flood slopes have been measured: 1903, 0.239 foot per mile; 1908, 0.174; 1909, 0.304; 1911, 0.174; and 1913, 0.174, for both the first and second rises. While gentler slopes now exist between St. Joseph and

Col. Townsend. Natchez than before this cut-off, the slopes have become steeper between Vicksburg and St. Joseph and between Natchez and the Red River Landing. Relative to Vicksburg, the low-water surface at St. Joseph has been lowered about 1.3 feet and at Natchez it has been raised 2.4 feet.

In the following table the distances from Cairo to Vicksburg, to St. Joseph and to Natchez are given as measured by the surveys of 1883 and of 1913; notwithstanding the cut-off, the river has regained its length, and the resultant caving of its banks has caused expensive levee re-location:

	Distance from Cairo, miles.	
Station.	Survey of 1883.	Survey of 1913.
Vicksburg, Miss.	599.3	601.8
St. Joseph, La.	648.3	661.7
Natchez, Miss.	700.3	705.7

In his work on the Rhine River, Jasmund defends the employment of cut-offs on the lower Prussian Rhine in the 18th century, because by the works of man the bends had been artificially made too great and the slopes too gentle, but criticises their employment on other portions of that river.

As to outlets, it is the experience on the Mississippi River that constant dredging is required, to keep them open. To be sure, bayous Lafourche and Plaquemine have been closed by levees, but Cubits Gap and The Jump practically have closed themselves, and the connection between the Atchafalaya River and the Mississippi has to be dredged annually to maintain a low-water channel. At low stages the velocity of flow through an outlet is less than in the main channel and a deposition of material carried in suspension occurs just as with overflowed banks during floods. However, if the outlet be made so large as to carry the main body of the water, then the original channel tends to fill.

Colonel Townsend states that in his opinion the use of levees as a means of flood control increases in relative importance toward the mouths of large rivers.

The Sacramento River affords a striking illustration of the principles enunciated above. Due to the great mass of detritus washed from the hills by hydraulic mining on its tributaries, the equilibrium which formerly existed between scour and fill has been destroyed and an enormous sand-wave is moving slowly down the river. As this sand-wave passes a given locality, the channel is choked and abnormal flood-heights are produced. Many years will be required to reproduce stable conditions.

To avoid the necessity of constructing excessively large levees on the main river, by-passes have been introduced to carry off a large proportion of the flood waters, which have to be leveed also. Above the by-passes the river is confined to a single channel through which the sand-wave is being driven. At a by-pass the force moving the sand-wave is dissipated, moving partially down the main stream and partially

through the by-pass. Steeper slopes must result in the main river to produce the same propelling force, and the navigability of the stream will be diminished unless the sand moved by the more efficient section up-stream can be removed by dredging, or the detritus deposited in the by-pass itself, thus reducing its carrying capacity. In the paper above alluded to, Mr. Engel maintains that a river under such conditions cannot be improved permanently by regulation. Col. Townsend.

The controversy on the raising of the bed of the River Po, mentioned by the author in Par. 66, was not whether there had been a change due to geological causes, as stated by Luigi Luiggi, but whether the change had been accelerated by levee construction. A recent paper by G. Fantoli (11 Po Nelle Effemiridi Di Un Secola, 1913) discusses the subject very extensively, and from the records of 1807 to 1907 he concludes that the changes observed in the leveed portions of the river are due to the use of water for irrigation, rather than to levee construction. A summary of the tables from G. Fantoli's paper is published in Professional Memoirs, Corps of Engineers (March and April, 1915).

Col. Wm. W. Harts,* M. Am. Soc. C. E. (by letter), states that flood control of the interior rivers of the United States is acquiring greater importance each year, as the localities through which the streams flow become richer and the cities along their banks more populous and valuable. There is no doubt that the devastation caused by floods is increasing; and from time to time public attention is painfully drawn by some shocking catastrophe to the necessity for more efficient flood control. As pointed out by the author, there is no evidence that floods are increasing either in height or frequency of late years; even though serious losses of life and property are more frequent. Col. Harts.

The urgent demand for more lands for agriculture and the enormous growth of cities along the banks have increased property values along the courses of many of the interior rivers, and thus have aggravated flood damages and made imperative remedies for flood control. If the public mind were not so soon restored to equanimity after these frightful floods and if it were not felt that the dwellers along the low banks are somewhat to blame in their lack of foresight in selecting these dangerous areas, it would be easier to institute some means of protection as a project of wide application. Nevertheless, there is a growing necessity for studying the various problems thoroughly, particularly those problems of a national character which properly come under Federal supervision. It is now impossible on many streams to undertake projects of a large extent, because the authority of one locality cannot be used against that of another and cooperation is often impossible, so that supervision of the work as a unit requires that a Federal organization should be used. The lack of coordination that usually exists among local authorities is only one of the reasons for Federal control.

The apportionment of the cost among the beneficiaries is a subject

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Col. Harts. that scarcely can be handled except by Federal control, and the proper relationship of the necessary public functions along the same stream (such as reclamation, flood control, navigation and drainage) cannot be observed efficiently by any other agency. In all flood-control work there are three parties in interest—the general public, the local or state organization, and the individual owners of property; and all three should contribute toward remedial projects in some fair proportion. Such a plan is now receiving attention for the Sacramento River, where plans for the improvement of navigation, flood control, reclamation and drainage are being elaborated with much skill and with every promise of successful fulfillment. The work is to be managed as a unit by the Federal Government and the cost is to be distributed among the owners of inundated land, the State and the Federal Government in the fairest way ascertainable. This plan already is a precedent and a striking example for similar work elsewhere.

Only a moment's scrutiny proves that such work should always be handled as a unit by a single organization. The various objects to be secured are all inter-related; for example, channels necessary for navigation usually are best situated near where channels of flood-flow are planned, and levees for reclamation usually are placed suitably for the control of floods. Therefore, all these functions palpably are managed best when contained in a single project under a single directing head. Hence it seems to be the logical and correct course to expand the duties of the engineers now charged with the work of improving and maintaining the river channel for navigation, so that the same engineers will control also the work of flood control, reclamation of inundated land, and drainage of overflowed areas; and in no other way can this work be undertaken so promptly, efficiently and successfully.

It is the strong conviction of Colonel Harts that all problems of flood control, with related questions of reclamation and drainage, should be studied as a part of a single project on each separate river, in conjunction with the project of channel building for navigation. The work should be carried out by the Federal Government under the engineer organization that has had so long an experience in navigation improvement of interior streams. Furthermore, the cost should be borne under some equitable division of expenses by the individual owners benefited, by the State governments affected and by the Federal Government—all in proportion to the benefits resulting to each—and such division should be provided for explicitly in the terms of the Federal act organizing the work. Such a policy would be practicable, logical and would give promise of the greatest efficiency.

Maj. Oakes. **Major J. C. Oakes,*** M. Am. Soc. C. E. (by letter), states that the author has produced a very valuable paper full of important and incontrovertible facts, and that there are but few expressions of opinion which offer opportunity for disagreement; but that the paper would have been

* Corps of Engineers, U. S. Army, Louisville, Ky.

still more valuable if it could have been amplified and not confined to the small limits of space allotted. Maj. Oakes.

In Par. 13 the author considers fallacious the belief that steepness of slope increases flood effect. However, besides the great flood problem relating to large rivers, there are innumerable minor problems relating to tributary streams. On such streams Major Oakes believes that increased rapidity of run-off (caused at least in part by steepness of slope) does increase flood effects, certainly at points where the slope is reduced and where channels are obstructed by natural conditions or artificial works. Similarly, artificial drainage and the clearing of forests ordinarily increase flood effects in the vicinity of the drained and cleared land by increasing the rapidity of the run-off, unless the channels below have had time to readjust themselves to the new conditions.

The author has not sufficiently emphasized the difference between floods on small streams near headwaters and those along the lower reaches of great streams like the Mississippi River. This distinction, explains many disputed points about the effects of forests, of reservoirs, and of steepness of slope. He has stated that great floods on lower courses of large rivers are results of ''fortuitous combinations of tributary accessions'', and explains how the retardation of the flow at the headwaters of a tributary may have no effect upon flood heights on the lower reaches of the main stream; but he does not make sufficiently clear that the detention of run-off at the headwaters of the stream, in most ordinary cases, would decrease flood heights immediately below the points of detention.

In his general conclusion about forests, the author states correctly that floods were as great when the country was covered with virgin forests as they are now and that modern reforested areas yield as much run-off as do similar areas of cleared land. His conclusion that no material assistance is to be derived from reforestation is agreed with, but he should have stated that while the existence of forests may cause greater flood-heights under certain conditions, under ordinary conditions forests do tend to equalize run-off. Forests may increase or decrease flood-heights, depending on saturation, snow, etc.; and, therefore, they cannot be counted upon to be effective in cases of great floods when control is needed most. However, it is the ordinary cases where forests do have some effect that impress themselves on the minds of the people, and that have caused the wide-spread belief that forests increase low-water flow and decrease flood-heights under all conditions.

Unless there are kept in mind the difference in the effect of forests and reservoirs in ordinary and in extraordinary cases and the different conditions existing near the headwaters and far away on the lower reaches of the main river, one is apt to reason by induction from his ordinary experiences from small streams to large ones, and from small floods to great ones. The author does not sufficiently make plain that methods which may be applicable to a tributary stream and usually may

Maj. Oakes. result in flood control for limited stretches of such a stream, would have no effect on the main river, because, as he states, floods in large rivers result from combinations of tributary flow.

The statement in Par. 27 that "the net tendency of human dealings with stream channels is to increase their carrying capacity" may be correct when referring to streams in foreign countries, and to navigable rivers in this country which are under strict governmental supervision; but the statement is believed to be incorrect with reference to non-navigable streams in more thickly settled communities of this country. Even in the case of such navigable streams as the lower Monongahela, lower Alleghany, and upper Ohio, it requires the unremitting efforts of Federal officers to prevent dangerous contraction of the present river channels. As to streams not under Governmental supervision, the only limit of increasing encroachments is that caused by their destruction by periodic floods.

It may be true that "piers properly built, extending well below scour, with all false-work removed, and with the channel bed left free of solid obstructions, are slight obstacles to flow"; still, the fact remains that generally piers are not properly built, do not extend below possible scour and that all obstacles in the channel bed are not removed. As a member of the Board of Officers on River Floods appointed by the Secretary of War to investigate the damage caused by the March-April, 1913, flood in the states of Ohio, Indiana and Illinois, the writer had the privilege of visiting most of the communities in those states that were damaged severely by that flood. At nearly every locality visited by the Board, the greatest destruction was caused by encroachments on channels and flood-plains, mainly by bridges and railroad embankments. It is not meant that if these encroachments had not existed, overflow would not have occurred; but it is true that little damage would have been done them aside from the overflow and wetting of valuable property. In the majority of cases bridges were too low, piers too close together, and abutments often set on or inside of the low-water lines. Earthen embankments without openings, except the bridged river channels, were built directly across the flood-plains and everything possible seemed to have been done to create barriers, with resulting elevation of local flood-heights. Many of these barriers ultimately were destroyed, in each case causing a wave to move downstream and sweep everything before it. It should be mentioned in this connection that a noticeable defect of nearly all the destroyed bridge foundations was that, when the material was sand or gravel, sheet piers were not used to enclose the beds of the foundations. Many bridges were wrecked by a scour of only a few feet under perhaps one edge of a pier that would have withstood the flood had sheet piles been used.

The writer feels very confident that nearly all damages due to floods in thickly populated sections of the country are due to artificial encroachments on channels. Even where the water overflowed great areas

of cultivated land in farming districts, like Indiana, the damage observed to such land was caused in all cases by the breaking of levees or of railroad and road embankments; wherever a break occurred, many acres of cultivable land were ruined. Maj. Oakes.

In Chapter 7 the author admirably discusses reservoirs, their functions and effects. Particularly important are his statements in Par. 43 as to the danger of conflict between private and public interests, if the reservoirs are to be used not only for flood prevention, but for other purposes also. If the stored water is to be used for power also and large moneyed interests are involved, it is extremely difficult for the public official in control of the operation of the reservoir or reservoirs to exercise his own judgment in their manipulation.

The discussion in Par. 48 of the combinations of tributary streams is excellent, though very terse, considering the great importance of the subject. The public does not generally understand the importance of combinations of high-waters in a large stream like the Ohio River. A stream whose channel capacity is sufficient to carry the floods of its tributaries without overflow if they arrive in succession, generally will prove too small to carry the floodwaters of those tributaries if the high-water from each tributary coincides with the flood crest on the main stream. As he states, the detention of floodwaters in a stream like the Miami may have a very important result at a point on that stream like Dayton, but very little result in reducing flood-heights in the lower stretches of the Ohio River. On the other hand, it should be noted that the detention of the waters of the Miami occasionally may even increase flood-heights in the Ohio near their junction. As to this, the District Engineer Officer at Cincinnati reported recently as follows: "A system of storage reservoirs on the upper Miami would not necessarily help flood conditions in the Ohio; in fact, it might at times increase flood-heights in the Ohio near the mouth of the Miami. The flood stage in the Miami in 1913 passed out before March 28. The high stage of the Ohio (at Cincinnati) was reached April 1. If the crest of the Miami flood had been detained to the latter date, a higher stage at Cincinnati would certainly have resulted". As Cincinnati is 21 miles above the mouth of the Miami, had the waters of the Miami been detained a few days, there would have been a considerable distance along the Ohio River ranging from above Cincinnati to many miles below where the flood-heights would have been even greater than those which occurred.

The above statement shows what might happen if reservoirs were being operated in an attempt to control the flood-heights of a great stream. It would be necessary in that case to have the floodwaters of each tributary under control and so to pass the detained waters that they would not combine to create a flood in the lower river. In the Ohio River Basin there are more than 260 tributary streams with drainage basins of over 100 square miles each; and for attempted control of floods in the Ohio there would be required several hundred reservoirs,

Maj. Oakes. all to be operated to the satisfaction of the people living in the valleys immediately below the dams and also so as to prevent floods in the lower Ohio. In the writer's opinion it would be beyond human capability for anyone to so control such a system as not to produce at some points along the stream higher water for short periods or high water for longer periods than would have occurred had there been no attempt at artificial control.

It is to be regretted that the author did not include in his paper descriptions of some of the flood-prevention works undertaken in Europe. Much has been said about these works, particularly about the use of rivers, and the results have been cited often as reasons why an attempt should be made to control floods in the Ohio and even in the Mississippi by reservoirs; hence it was hoped that the flood-prevention works of Europe would be described and comparisons made between some of the adopted projects there and the very much greater problems in the United States. Without going into details, it may be said that the European projects so often mentioned relate to streams similar in size and drainage areas to the small tributaries of our great river systems. The successful application of a reservoir system to a small stream cannot be adduced logically as a reason for the adoption of a similar system for streams like the Ohio and the Mississippi.

In Par. 57, the author states that the general belief that cut-offs "bring more water in a given time to the lower portions of the valley" is unfounded. However, that statement may be correct, or not, depending on circumstances. If there be considered a single cut-off or a number of cut-offs where the quantity of water received at the head of the improvement is no greater in a given time than before, then the quantity delivered at the lower end of the improvement will not be increased. An example of this would be the straightening of the course of a river and the leveeing of the stretch straightened for the purpose of reclaiming the adjacent bottom lands. Generally, however, cut-offs are used to relieve flood situations by increasing the rapidity of run-off from points where the water has been held back by barriers and by channels of small capacity; and under such conditions, a greater quantity of water will be received at the head and delivered at the lower end of the improvement than before the improvement was made.

By using cut-offs, the length of the stream is shortened; the slope, the velocity, and the capacity of channels of the same cross-section are increased; and the discharge for the same gage-height at a given point is made greater. If the river be improved throughout its length by increasing slope or discharge area, thus making provision at all points for the greater discharge, then there will be no piling up of the waters. Usually, however, such improvements are not carried out uniformly throughout the length of the river and a point or points exist where more water arrives per unit of time than under former conditions. This water cannot escape as fast as it arrives without increasing the dis-

charge area of the channel below by erosion or increasing its surface slope. The latter means that flood-heights must be increased at such points. Apparently the only exception would be where a stream overflows the whole flood-valley, in which case the sinuosities of the channel in the valley would have practically no effect on the discharge. Maj. Oakes.

Referring to the author's discussion of conflicting jurisdiction, Par. 74, a case under the writer's observation may be of interest as showing how difficult it is properly to control the construction of works affecting flood-heights, and illustrating the need of definite control by the Federal Government of such situations. At a town on the Wabash River where a through truss-bridge was destroyed in the March-April flood of 1913, the County Commissioners proposed to build a reinforced-concrete structure having a much smaller discharge area than had the destroyed bridge. High-water had reached well above the floor of the old bridge, drift had collected, forming a partial dam, and the floodwaters had been deflected through the city streets. Ultimately the truss had been carried off, releasing the drift and relieving a very serious situation. The County Commissioners planned to build a structure that would not be destroyed under similar circumstances; and the people most interested objected very strenuously to the construction of the bridge as planned, on the ground that it would increase flood damage in the town very materially. Unsuccessful efforts were made to prevent, by injunction, the construction of the bridge as designed. The townspeople then requested the Federal Government to interfere under the authority granted to the War Department to control the construction of bridges over navigable streams. The Federal Government notified the County Commissioners that the Wabash River is a navigable stream, that any bridge constructed over it without the authority of the Secretary of War would be an illegal structure subject to removal, and that its builders would be subject to criminal action. The County Commissioners denied that the Wabash is navigable at the bridge-site and proceeded to complete the bridge. There is considerable doubt whether the stream is navigable at this point under present laws; hence it is doubtful whether the Government can do anything to relieve the situation. What the result will be in the case of another flood similar to that of 1913 can be imagined only; but it is safe to say that the flood-height in the town in question will be much greater than it ever has been before, with increased velocities through the streets and the possibility of a catastrophe.

The flood problem is a national one and should be controlled by the national laws. This does not mean that the Federal Government should bear the cost of all the flood-control projects in the United States, but that the people should be protected by Federal Laws from dangerous encroachments of river channels, and flood projects should receive the scrutiny and approval of some Federal authority. At the present time the War Department is attempting to prevent dangerous encroachments on the navigable portions of navigable streams, on the ground that ero-

Maj. Oakes. sion and floating debris resulting from such encroachments injure the navigable portions of the rivers. As it is almost impossible to show definite damage to the lower part of the stream because of any particular encroachment and as there are no laws upon which to base any action except those relating to navigation, the Federal officers are placed in an anomalous position and any control exercised thus is bound to be inefficient. As the author states, if the power properly to exercise this control does not exist under the Constitution, then the Constitution should be amended.

In Part II the author presents concisely a large fund of information relating to some of the flood problems of the United States. This information has great reference value and is necessary to a correct understanding of the problems described. The few opinions about these problems expressed are so well founded that there is little opportunity for disagreement or discussion.

Mr. Grant. **Mr. Kenneth C. Grant,*** M. Am. Soc. C. E. (verbally), stated that he disagrees with Major Oakes regarding the importance of the flood effects due to obstruction of streams by bridges. The flood of 1913 at Dayton, Ohio, reached a discharge of about 7500 cubic feet per second, and the intensity of the flood would not have been reduced appreciably, even if all the concrete bridges in the vicinity had been removed. In fact, at Hamilton, Ohio, all of the bridges were washed out on the afternoon of March 25, 1913, and soon afterwards the flood-height there rose instead of falling.

Referring to the flood-control work at Dayton, Ohio, the drainage area of the Miami River and its tributaries above Dayton is about 2500 square miles. It is now proposed to regulate the flood-flow of the Miami by five instead of seven (as formerly proposed) detention reservoirs, these five having a total flood area of about 30,000 acres. In the 1913 flood, the total area flooded was 101,000 acres, about 24,000 acres of which were included in the five reservoir sites proposed. Construction of the proposed reservoirs is to proceed under the Conservancy Law of Ohio, that act having been upheld by the Courts.

He is not sure that the control of the Ohio River by detention reservoirs above Dayton is impracticable.

The control of river discharge both by closed and by detention reservoirs is practiced extensively in Germany and Hungary. The problems there, however, are smaller than those of the large rivers of the United States and consist principally in preventing undue erosion by check dams—though there are applications of this method to prevent floods and also to increase the low-water flow. The German and Hungarian developments have been uniformly successful. It is worthy of note, however, that there no project is undertaken along a stretch of a river without planning it as a component part of the general scheme for the control of the river as a whole. This practice prevents a local

* Asst. Engr., Miami Conservancy Dist., Dayton, Ohio.

benefit for one region from becoming a possible menace to another locality on the same stream. Mr. Grant.

Mr. Dabney. **Mr. T. G. Dabney,*** M. Am. Soc. C. E. (by letter), states that he has devoted the greater part of his professional career almost exclusively to the lower Mississippi River problem, and hence will confine his comments merely to that part of the author's paper treating of that river and of the phenomena and physical attributes from Cairo south to its mouth.

The Lower Mississippi River is not one of the "large rivers flowing in beds of their own alluvium" as the author seems to imply—though this is a fallacious belief widely prevalent in relation to the Mississippi River; this river at its birth, terminating a cataclysmic geological period, carved for itself a channel through a pre-existing formation of the "Port Hudson" age. This statement is made on the authority of the late General Humphries, Corps of Engineers, U. S. Army, Dr. E. W. Hilgard, Dr. E. A. Smith and Dr. F. V. Hopkins—all eminent geologists—and because of the personal observations of Mr. Dabney in this field. However, this geological fact perhaps is immaterial for the purposes of the present discussion, as it is true that the bed and banks of the river are composed of formations which yield readily to the erosive energy of the current.

Under the head of "Cut-offs", the author enunciates certain principles with which Mr. Dabney takes issue. Quoting in part from Par. 55: "Sinuosity of channel is a characteristic of all streams and in some instances is developed to an extraordinary degree. In large rivers, flowing in beds of their own alluvium, the opposite processes of developing bends and of cutting them off are in active operation; but on most streams the process of change has largely ceased, the bends are comparatively permanent, and the existence of excessive sinuosity is, at first thought, inexplicable. * * * * Almost invariably the slope is very slight and generally the channel capacity wholly deficient for the ordinary flood flow. Neither in this class of streams nor in those in which channel changes are in active progress is the operation in its origin other than accidental. To say that the process is 'necessary', that bends 'must' occur, as engineers often express it, is no more justifiable than to say that ruts in a road must occur where they do, or must even occur at all. Left to themselves these things do occur, but with guidance or restraint at the right time they might easily be prevented, or be made to occur in different places or directions".

In laying down a general principle to account for sinuosity in streams, General Chittenden holds that sinuosity is "accidental" in its "origin"—that bends do occur in rivers, but not necessarily; and in treating this part of his subject he appears to have fallen into some confusion in considering nature's phenomena pure and simple and as modified by man. The closing suggestion quoted above simply means that

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Mr. Dabney.

man may interpose his hand in nature's processes, and by injecting special causative agencies may obtain modified results. In the quotation from the author above, he appears to have discarded what has long been axiomatic—that accidents are wholly foreign to nature's economy, and that all of nature's processes and results are in strict conformity to the inexorable law of "cause and effect".

The numerous sinuosities and "horse-shoe" bends that characterize the lower Mississippi River are the direct result of the operation of compelling natural laws. The factors involved are: (1) The volume of flood water discharged, (2) the horizontal distance to be traversed, and (3) the vertical difference between the termini of the particular portion of the river under consideration.

The interaction of these factors inevitably must produce the conditions that we find. The erosion of the banks on alternate sides of the river from which sinuosity ensues is responsive directly to velocity of flow. Velocity is dependent on slope, and slope is the resultant of fall and distance combined. With local shortening of distance and steepening of slope, due to "cut-offs", the increased velocity of flow and energy of current make tremendous inroads into the banks, thus, within the region affected by the local change of regimen, developing new bends and lengthening the existing bends, until comparative equilibrium among the conflicting forces is restored by a regaining of the length of channel lost temporarily by the cut-off.

Nature has been engaged constantly throughout the history of the Mississippi River in an endeavor to establish perfect equilibrium between the three factors that control its regimen, by extending the process of sinuosity until a maximum length shall be attained with a resultant flat slope, and a current energy arrived at too feeble to cause further erosion.

This attempt to establish an equilibrium has been interrupted continually by "cut-offs" in different localities along the channel length, and at no great intervals of time; so that the river has been compelled to do its work over again in perpetuity in the localities so disturbed. The theory held by the uninformed, that the modern Mississippi River transported and deposited the entire content of the "Mississippi Embayment" where it is now found, carries with it the belief that the river channel has traveled east and west, and traversed the whole width of the basin.

Hilgard points out that these lateral movements of the river channel have been confined to a comparatively narrow belt along the axis of the stream-flow, defined by an axial alluvial ridge which is 10 to 15 feet higher on the immediate banks of the river than the terrain outside of its limits. The maximum width of this belt with its superelevation due to modern alluvial deposits is approximately 10 miles, and within this belt all of the lateral oscillations of channel alignment have occurred. This can be well realized when it is considered that the extension bends by caving banks to the eastward and westward have been counteracted

continually by "cut-offs", by which such local lengthening is nullified and the channel brought back nearer the axial line. These two antagonistic agencies have been engaged actively in doing their own and undoing each other's work since the development of the modern Mississippi River, with a generally balanced resultant as shown above. Mr. Dabney.

The author says further in relation to "cut-offs" (Par. 58): "The mistake generally made in resorting to cut-offs is in not properly estimating and providing beforehand for the temporary disturbing effects likely to follow. Misfortune which might easily be avoided at small expense often results from neglect of this precaution". The writer does not challenge the above statement except as to large rivers flowing between easily erosible banks. In the Lower Mississippi, even under normal conditions with apparently balanced forces, the problem of combatting bank erosion in the great bends where the shifting of the shore line may be 600 or 800 feet for several miles of lineal extent in a single year, is sufficiently formidable even without cut-offs; and with the greatly magnified current energy near a cut-off, measures to combat the destructive agencies would be wholly impracticable.

As the result of the writer's long practical familiarity with the Mississippi River problem, he has a settled conviction that methods used for its regulation and control must be confined (if they are to be successful) within the limits of the strictest conservatism, with no element of coercion whatever.

The questions of "reservoirs", "by-passes" and "outlets" as means to control the floods of the Lower Mississippi River have been threshed over repeatedly for the past half century; and may be disposed of briefly by the statement that in the consensus of opinion of those engineers who have been in direct touch with this problem, but little can be hoped for from those methods of control; and that the most readily available reservoir space to contain the surplus flood-water is to be found between lines of levees, on opposite sides of the river, built up to the height required to give sufficient capacity.

Referring to Par. 65 of the author's paper, the conclusion stated therein as to the uncertainty of future "flood-heights" because of restraint by levees, doubtless is true as applied to the Lower Mississippi if its entire length is considered, as the effect of some of the "variables" in the problem cannot be foreseen. These "variables" are the flood contributions from three large tributaries (the White River, the Arkansas and the Red), the first two discharging through the same mouth at a channel distance of 400 miles below Cairo. The run-off from the east and west watersheds between Cairo and the Arkansas River is not great enough to affect flood-heights appreciably; and the controlling flood-impetus passing by Cairo is projected through this lower portion of the river. The writer's work in flood-control on the Mississippi River has been throughout this part of the river.

Mr. Dabney.

In 1906, for the first time in the river's history, a moderate flood passed all the way from Cairo to the Gulf with no water escaping from the channel over the levees. This was recognized by the writer as being the first occurrence of a stable datum plane for reckoning future flood elevations that ever had been presented in the Mississippi River problem. The 1906 H.W. passed Cairo with a gage-height 7.8 ft. below the maximum height of 1913. A much greater flood followed in 1907, which also passed all the way to the Gulf without appreciable escape of the floodwater beyond the levee lines. The 1907 flood-height at Cairo exceeded that of 1906 by 3.7 ft. There was substantial parallelism along this part of the river between the high-water profiles of these two years, so that it was unnecessary to modify grade-lines based upon the 1906 datum in order to conform to the higher flood profile of 1907.

The writer has assumed with much confidence that any future flood confined between levees shall develop a profile between Cairo and the Arkansas River substantially parallel to that of 1907, leaving but one variable in the problem, the maximum flood flow past Cairo. In 1912 the maximum at Cairo exceeded the previous record 28%.

The writer has adopted an ''ultimate'' grade-line for the levee with a margin of 3 feet above the ultimate flood-plane as deduced above, which is relied on to afford security against the possible though not probable excess of flood-flow above that of 1912.

Building levees along the Mississippi River high enough and strong enough to contain any floods that may be anticipated is merely a question of cost. In the use of such heterogeneous materials as those composing levees, absolute security can be obtained only by using a generous ''factor of safety'' in proportioning the cross-section of the levee; and only the goal of absolute security justifies very large expenditures for flood protection.

A very vulnerable feature along a large extent of the levees, especially in the upper portion of the basin, is the instability of the foundations. This is due to the existence (underlying the base of the levee) of deep strata of sand, and sometimes of gravel, beneath a crust of clay, and constituting a permeable stratum through which water flows freely under hydrostatic pressure, wherever orifices through which the water can escape are developed on the land-side of the levee base. In one locality in the writer's territory, soundings 35 feet deep failed to penetrate entirely the underlying permeable formation.

For many years past the writer has used a method of controlling this vulnerable feature of levee protection, which has proved entirely and permanently successful. This is a simple device of ponding water over treacherous areas by means of sub-levees behind the main levee. This treatment both reduces the velocity-head and places a dead-water ''cushion'' over the orifices of the ''geysers'', which prevents the dispersion of any displaced material that may be brought up by the underflow. Siphons are used to hasten the filling of large basins (several acres in

Mr. Dabney.

area) where the filling is too slow by natural process. These principles of foundation treatment have been very extensively used in the Upper Yazoo District, with entirely satisfactory results and at a cost less than one-half percent of the cost of the main levee.

The problem of flood control in the Upper Mississippi Valley is a simple one, from an engineering standpoint, and embraces only two separate lines of constructive work, to-wit:—bank revetment, to give permanence to the shore-lines and fixation to the line of flood flow; and adequate levees on the opposite sides of the river to confine the flood water to the channel. The work of improving the channel for navigation is inseparable from that of maintaining permanent levee lines, both depending absolutely upon a cessation of bank erosion and the resultant permanence of the shore-line.

In order of time, bank revetment logically should take precedence over levee building, but by force of circumstances the latter became dominant in the field of flood protection before the problem as a whole came under the view of engineers; and this fundamental factor of bank protection has been allowed to lag far behind its proper status up to this time.

The author states that the volume of earth dropping into the river annually from caving banks is estimated at 900,000,000 cubic yards, which estimate does not appear to the writer to be extravagant. The bulk of this great volume of earth after tumbling into the current is transported but a few miles and is again deposited in the channel, much of it on the submerged dams, called "crossings", at the foot of the bends. The material so shifted from the banks to the channel during floods must act directly to diminish the discharge capacity of the channel and must raise correspondingly the elevation of the flood-plane. On the other hand, the complete withholding of this heavy burden upon the flood service of the river, and the resultant loadless flood flow, would have the effect of a progressive augmentation of discharge capacity, and permit increase of depth on the "crossing" and a lowering of flood elevations—all with a consequent simplifying of the levee-control feature.

As an incident of bank caving, there is a very serious handicap on the navigation of the river between Cairo and the Red River. This handicap is that it is not practicable to erect freight-handling facilities along this part of the river with any assurance of the permanence of their functions. The experiment made years ago of building large elevators at Memphis and Vicksburg came to a disastrous end in each case, because caving banks several miles distant from the sites of these elevators caused changes of the river channel that rendered the elevators wholly inaccessible to steamboats.

Mr. Dabney discussed briefly the portion of the author's paper relating to the Sacramento River problem, both he and General Chittenden having been members of the Engineering Commission which reported on this problem in 1904.

Mr. Dabney. The plan finally adopted for the treatment of the Sacramento River, that recommended by the California Debris Commission, differs essentially in one feature from the plan set forth in the report of the "Dabney" Commission in 1904.

The 1904 plan contemplated, as an initiatory measure, accommodating as large a flood flow within the main channel of the river confined between levees as might be practicable economically—the surplus water only to escape over spillways into by-passes, the leading idea being to augment progressively the discharge capacity of the channel by a combination of natural and artificial agencies—with the expectation that it should be capable ultimately of carrying the maximum flood flow then in view. However, the maximum flood flow contemplated in 1904 proved to be only about half as great as that which occurred in 1907; and the plan adopted relies upon by-passes as a permanent feature to take care of by far the largest part of the flood flow, leaving the river channel with its present limited discharge capacity.

The writer sees no good reason for not combining the two principles in the present plan, and thus making the river channel carry a progressively increasing part of the flood flow, relieving the by-passes to that extent, and acquiring capacity after a time to carry ordinary floods into Suisun Bay between the confining levees—and bringing the by-passes into play only upon the occurrence of extraordinary floods.

Mr. Wadsworth. **Mr. H. H. Wadsworth,*** M. Am. Soc. C. E. (by letter), states that the author has covered this subject so comprehensively, both generally and specifically, that in discussing the paper he desires only to emphasize one or two points and to correct one or two impressions which, from events subsequent to the gathering of data for the paper, perhaps may be slightly in error.

Forest Theory. The author has shown conclusively in this and in earlier papers that there is no substantial basis for the popular belief that deforestation has aggravated flood conditions and that reforestation will alleviate them; and his findings in this respect should be published as widely and emphasized as much as possible to correct this faulty belief. When the publication of articles showing this pet theory to be erroneous leads to severe criticism of their author by a President of the United States, as has happened, the magnitude of the task of reversing public opinion becomes apparent.

Storage Reservoirs. A considerable study was made by Mr. Wadsworth of the possible relief from flood conditions obtainable by storage reservoirs, and of the relative cost of such reservoirs as compared with other methods of securing an early measure of relief; this study showed that in California the use of reservoirs for this purpose alone is impracticable, except perhaps on one or two minor but bad-acting watersheds. If a reservoir is to serve both for flood control and for irrigation or power, only that portion of its capacity in excess of the other require-

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Mr. Wadsworth.

ments can be counted on as available for flood control. Unless governed by accurate information as to the extent and temperature of snow-covered areas, the depth and condition of snow, the prevailing meteorological conditions, and the stage of waters on the several tributaries, the regulation of discharge from a reservoir may result in raising, rather than in lowering, the peak of the flood wave.

Sacramento River Problem. As stated by the author, the Sacramento River Flood Control Project proposed by the California Debris Commission has been adopted (with some slight modifications) by the state of California, and legal machinery has been created for carrying out such portions of the work as are to be paid for by assessment on properties benefited. The plan has been approved by the U. S. Board of Engineers for Rivers and Harbors, but as yet Congress has made no appropriation for the work.

Former hydraulic mining operations resulted in depositing vast quantities of debris in the Sacramento River and its tributaries. For nearly two years past two large suction dredges have been removing this debris from the River to restore previous conditions as far as practicable. These two dredges have a monthly capacity each of from 300,000 to 400,000 cubic yards per month, and their work is being done under an earlier project of the California Debris Commission for removing mining debris from the River. Incidentally, this dredging work is increasing the flood-carrying capacity of the lower river and will fit in with the later and larger project.

At present the vexing problem hardly seems to be in such a fair way to early solution as appeared to be the case a year ago. Suits have been instituted involving the constitutionality of the State Act, and injunctions have been granted against carrying out some of the works authorized by the State Reclamation Board. However, there is encouragement in the fact that even those who are opposing certain specific works or acts express approval of the project as a whole. If the delays caused by these Court contests result merely in delaying the withdrawal of large areas from flood overflow or reservoir storage in the upper part of the Valley until much greater progress has been made in enlarging the outlet, and thus prevent the precipitation of increased discharge for a given total run-off, then final good rather than harm may result from the delay.

San Joaquin River Problem. The San Joaquin River (which drains the southerly portion of the great central valley of California and unites with the Sacramento River at the head of Suisun Bay) at present has a much less acute problem than has the Sacramento River. This is because its watershed receives a much smaller precipitation, and because its mountain portion is higher and, hence, a larger portion of its precipitation is in the form of snow at altitudes too high to permit its being carried off by warm rains. As yet no attempt has been made to reclaim a large portion of its bottom lands. These are used largely for grazing purposes in the late summer and early fall, and serve as admirable re-

Mr. Wadsworth. tention reservoirs in the winter and early summer. During most years, the maximum rate of run-off occurs in June, though severe or disastrous floods usually have occurred in January or February.

The island lands of the delta region now are practically all leveed, though with numerous natural and artificial waterways gridironing them; and the prospective reclamation of bottom-lands extending some hundred miles above the delta, gives rise to a problem fully as difficult as that of the Sacramento. This is because the natural outlet of the San Joaquin is throttled similarly to that of the Sacramento, and the island lands are of such nature (peat underlaid by mud) that they will not support the weight of levees of any considerable height.

After assigning their full flood flows to the many interconnecting watercourses of the delta (with their banks raised by levees as high as practicable), there still remains the necessity for by-passes. These by-passes will not have to be so large nor so long as those of the Sacramento, but will be more difficult to secure, because the land is practically all under cultivation, and not waste land as is most of that through which the Sacramento Valley by-passes are located.

The San Joaquin situation will better lend itself to development by steps, if the reclamation of its up-river lands in large units can be avoided.

Mr. Grunsky. **Mr. C. E. Grunsky,*** M. Am. Soc. C. E. (by letter), states that General Chittenden has made it clear that the solution of the problem of flood control must conform to local conditions, and has shown the folly of placing dependence upon either reservoirs or forests as sole or even major measures to control floods. The paper is of special value to the engineering profession, not so much on account of its scientific discussion of the cause of floods and of the measures which may be resorted to to mitigate their destructiveness, as because it will encourage a study of the various methods of procedure as adapted to any particular problem.

Mr. Grunsky states that he is so fully in accord with what General Chittenden has presented that his contribution to the discussion will be confined to a single subject, that of the flood control of the Sacramento River, California.

Before a project of flood control is finally adopted, more thorough studies should be made of the volume of flow that will be presented under regulated conditions than engineers in the United States are accustomed to. The need of such studies was felt some 35 years ago when Mr. Grunsky, as Assistant State Engineer of California, was confronted with the problem of predicting (from data relating to the flood discharges of numerous streams entering the Sacramento Valley) what the flow down the Valley would be if all the flood waters were confined to definite channels. The studies then made became the foundation for the use of the mass-curve in connection with the study of river discharge, as affected by the withdrawal of the water into natural overflow basins. This

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Mr. Grunsky.

method of using mass-curves has been explained at various times and need not be dwelt upon here.* Attention should be directed, however, to the effect upon the discharge at down-river points, if some of the area subject to occasional natural overflow can be maintained permanently as an area to be flooded in case of emergency. There is no more effective way of reducing the flood flow on the lower reaches of a river than by connecting with the river one or more lateral basins which will be thus filled, and which will rise and fall with the river only at times when the river discharge otherwise would exceed the capacity of its lower reaches.

In the case of the Sacramento River, the withdrawal from natural inundation of basins having a combined water-surface area at flood-stage of about one thousand square miles, would increase the flood flow of the lower river from about 200,000 to more than 500,000 second feet.

If those basins were not allowed to receive any water until the river actually is at a danger stage (that is, if the excess water were allowed to leave the river only under control), then the proportional effect of the basins on the flood flows down-river would be still greater.

Some of the basins are so low in elevation that if once filled they could be drained but imperfectly until late in the season. Others (as the Butte Basin, east of the Sacramento River above the Marysville Buttes, and the Upper Colusa Basin, in the same region on the west side of the river) are so situated that after filling, their inundation would not be protracted. To a lesser extent this is true also of the Sutter Basin, which lies between the Sacramento and Feather Rivers.

The complete reclamation of all those basins has been made a part of the flood-control project of the Sacramento River submitted by the engineers of the U. S. Army, constituting the California Debris Commission, as approved by the legislature of California. This flood-control project is accepted generally as the best that can be offered; nevertheless, before its final execution, serious consideration should be given to the question of whether it will be wise to protect all of the land on the east side of the Sacramento River against extreme floods—except of course the land to be left in the by-passes. The question is raised as relating to the east side of the river and not the west side, only because reclamation on the west side has been further advanced.

Here is an opportunity for close study which will involve not alone physical but also economical problems. This question is referred to, not for the purpose of suggesting a solution, but merely to show that similar problems may also be found on other rivers, as yet unsolved.

Mr. Norboe.

Mr. P. M. Norboe,† M. Am. Soc. C. E. (verbally), stated that it is not generally recognized that the Sacramento River is the fourth largest flood-stream in the United States. He stated that bank protection is chiefly a matter of the cost that can be afforded.

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*Report of Commissioner of Public Works, California, 1895; Transactions Am. Soc. C. E., Vol. LXI, p. 332.

† Assistant State Engineer, Sacramento, Calif.

Mr. Givan. **Mr. Albert Givan,**† Assoc. M. Am. Soc. C. E. (verbally), stated that from all data obtainable, it is conceded generally that the floods on the Sacramento in 1862 exceeded those of 1907 and 1909 by about 50%; and that on the Feather and American Rivers, tributaries of the Sacramento, the floods of 1862 exceeded those of 1907 by about 20%.

Mr. Gideon. **Mr. A. Gideon,*** M. Am. Soc. C. E. (verbally), referring to the effect of detention reservoirs on flood-heights, stated that the City of Manila, located on the River Passig (a stream having a normal discharge of about 6000 cubic feet per second) has experienced three floods during the last 12 years, the most severe of which was the flood of July, 1914. Referring to the effect of stream obstructions on the height of the flood-stage, it was noted that during the 1914 floods, the effect of the Bridge of Spain (a masonry-arch structure located about three quarters of a mile above the mouth of the Passig River) was such as to produce a difference of water-level between the upstream and downstream sides of the bridge equal to 3 feet.

Referring to the action of the lakes within the flood-plane of a river as regulators of the flood flow, the observed effect on the River Passig at Manila during the 1914 flood was as follows: On the Passig, about 25 miles north of Manila, there is a diversion dam built for water-supply purposes. Measurements of the head of water flowing over the crest of this dam during the flood indicated a discharge there of 60,000 to 70,000 cubic feet per second, estimating the flow by the use of river coefficients derived at Cornell University and elsewhere. For the purpose of estimating the flood flow at Manila, the high-water marks during this flood at Manila were noted carefully; and the estimates showed the maximum flood at Manila to be no more than 40,000 cubic feet per second.

The 25,000-30,000 cubic feet per second smaller flood flow at Manila than at the diversion dam is explained as follows: The drainage area of the Passig is about 4000 square miles, and below the diversion dam in the valley of the river there is a lake of about 400 square miles (these areas are approximate only, as there are no surveys of this region as yet). The higher discharge at the dam backed into this lake and the lake acted as a detention reservoir, and thus diminished very appreciably the maximum flood-height at Manila—though at the same time extending the period of actual but lesser flood-height there. In this instance there was only one lake reservoir; had there been several, a combination of the discharges from them possibly might have proved as great and as disastrous at Manila as the total flood occurring at the diversion dam and unrestrained by lake storage below.

Mr. Sellew. **Mr. Francis L. Sellew,**‡ M. Am. Soc. C. E. (by letter), states that the paper is a most excellent general statement of the principal flood control problems in the United States at the present time; but the limited space

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*Chief Engineer, Board of Water-Supply, Manila, P. I.

‡ U. S. Reclamation Service, Yuma, Ariz.

to which it is confined has necessitated the elimination of much technical detail which would be of interest to engineers, though its present condensed form will perhaps better attract the general reader. Mr. Sellew.

The author's statement in Par. 65, that "levees do have the effect of increasing flood heights", is not generally true and should be qualified. Levees do exclude the flood discharge from large areas of bottom-lands, which may have exerted some reservoir effect prior to the building of the levees; but whether such confinement of the water will raise flood-heights or not depends entirely upon the conditions surrounding each case.

The Colorado River at Yuma, Arizona, has been leveed from the Laguna Dam to the Mexican boundary, a distance of some 40 miles; and the floods are thereby excluded from about 100,000 acres of bottom-lands which formerly were flooded to a depth of about 4 feet, with a total storage of 400,000 acre-feet. The maximum recorded flood of the Colorado River is 150,000 second-feet or 300,000 acre-feet in 24 hours. Such a reservoir capacity could exert no appreciable effect upon flood-heights, because the bottom-lands always were filled before the critical stage of the flood was reached; and even had this small storage capacity been available at the flood peak, it would have been exhausted in about 30 hours and before the beneficial effect appeared on the gauge.

In describing the Colorado River problem, the author limits his attention to that portion of the stream between Yuma and the sea, apparently considering that the only area which needs protection is the Imperial Valley, in which the agricultural activities during the last 12 or 14 years have been very intense. However, the Government is now engaged on a project to reclaim 150,000 acres near Yuma, has under consideration the reclamation of the Parker Indian Reservation of about 200,000 acres, there is an opportunity to reclaim about 50,000 acres near Needles, and about 100,000 acres in the Palo Verde Valley are being reclaimed by levees and irrigation system by private effort; hence, it appears that the control of the Colorado involves other districts fully as important as the Imperial Valley.

Before the communities named can be developed properly, the Colorado River must be able to pass to the sea, without menace to the adjacent territory, all of the water which may come to it.

Considering first the plan of flood prevention, which consists of holding back in the reservoirs all of the flood discharge which would exceed the capacity of the channel:

From 1902 to 1914 ten annual floods have overflowed the banks of the Lower Colorado, the yearly discharge above the bank-full stage ranging from 80,000 acre-feet to 7,000,000 acre-feet. In five of those ten years, the year's overbank flow has exceeded 2,800,000 acre-feet. Hence, to control the floods completely by reservoirs, there must be available at the beginning of the annual freshet a reservoir capacity of 7,000,000 acre-feet, which will cost at least $5.00 per acre-foot, or a total of

Mr. Sellew. $35,000,000. Such an expenditure would do merely what levees will accomplish (keep the river within banks), and the revetment of caving banks still will be necessary, for erosion goes on at all stages.

When attention is given to flood protection by levees, it appears that all the districts named above will require but 200 miles of levees with an average height of about 8 feet; these levees can be built for about $13,000 per mile, or for a total cost of $2,600,000. Hence, levees will accomplish for less than three million dollars a result which with reservoirs will cost 12 times as much. The caving banks can be revetted with rock placed from railroad trains operated along the tops of the levees. Quarries are available within 25 miles maximum haul. Based upon several miles of such work which has been actually built, complete revetment may be had for not more than $40,000 per mile, and the entire 200 miles of levee may be protected permanently for not to exceed $9,000,000, including the cost of the railroad track.

The above will be required whether reservoirs or levees are used; but it may be stated that the entire cost to control the Lower Colorado permanently with levees protected by rock revetment will be less than $12,000,000.

Because of the enormous silt burden which the Colorado carries, reservoirs are out of the question except on the upper reaches of its tributaries, where the water is fairly clear. Examinations disclose the fact that the available storage on the Colorado is very meagre, only about enough to satisfy the irrigation requirements; and that the available reservoir capacities cannot be depended on for flood relief. Reservoiring may assist to some extent, but experience indicates that the only sure prevention of flood damage is flood protection by levees.

When this levee protection is accomplished, the Imperial Valley will be protected along with the other districts, and as the complete improvement can be accomplished for $12,000,000 it should be no great task for the Imperial Valley to provide its fair share of the cost.

There are one million acres within the United States depending upon the control of the Colorado River, and this land will have an ultimate value of at least $200 per acre, or will have a total value of at least $200,000,000. Hence the cost of levee improvement would be but 6% of the value of the protected area; and should the Government advance the money and receive it back in 12 years without interest, the annual charge would be only one half of one percent of the value of the land. This is no more than is paid annually in some communities for fire insurance, a continuous tax without hope of ultimate protection.

If the money be made available, the work can be accomplished quickly. When the work is authorized, the location of the levee protecting the Imperial Valley must be fixed, which involves a choice between the Volcano Lake region and the margin of the old river. If the former be selected, a new river channel must be built, and if the latter, the old channel must be repaired. Mr. Sellew believes in returning the river to

its old course and channel, as such action would produce the desired result at less cost than the Volcano Lake location. Mr. Sellew.

On streams, the beds of which are scoured readily by floods (such as the Colorado), the confinement of the current to channels of normal widths by means of levees improves greatly the hydraulic conditions, the tendency being toward lowering flood-heights rather than toward raising them. It may be true that the confinement to a channel within levees has been followed in some instances by higher gage readings, but even with such enormous basins along the Mississippi as the St. Francis and the Yazoo, engineers still are divided in their opinions on this point.

A paper on "The Discharge of the Mississippi River" by William Starling, Transactions Am. Soc. C. E., November, 1895, states as follows:

> "The influence of the vast unleveed front of the Saint Francis Basin on the discharge and on the gauge height at Helena and at points below is indeed a question which is not well understood, and upon which opinions have been divided. It has been reasoned out on various lines. It was for a long time maintained by levee engineers and by the author, among others, that the effect of leaving the front of this great reservoir open was rather to increase the discharge and the height of the flood line at the foot of the basin. * * * * *
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> This position was disputed some years ago by Captain Rossell and has lately been attacked with much ability by Captain Townsend. These engineers draw their arguments from the relations known to prevail between the different gauges. For instance, a comparison is made of the Cairo and Helena gauges, care being taken to select the crests of rises or the extreme low points of falls, so as to readily identify the corresponding points and not be forced to apply a somewhat doubtful time interval. It is found that for all stages from zero to bankfull, there is, on the whole, a striking parallelism between the gauges, Helena being usually a little higher. * * * * *
>
> At stages beyond the bankfull, however, this relation ceases. Cairo then becomes the higher, and this by a constantly increasing quantity with the magnitude of the rise so that in 1882 it was 4.7 ft. above Helena. In 1893 it was only 1.4 ft. above. This remarkable departure from previously existing relations is ascribed by Captain Townsend to the influence of the Saint Francis Basin acting as a reservoir. According to this view the water abstracted from the upper end of the basin is retained in the reservoir a sufficient time to allow the crest of the flood to pass Helena before it is returned. When it is returned it is not in sufficient quantity to raise the flood line to the height which it would have attained in a confined state. * * * * *
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> The plain consequence to which this reasoning leads is that if the front of the Saint Francis Basin were completely sealed by

Mr. Sellew.

levees, the gauge at Helena, in long continued floods, would eventually attain a height at least equal to that reached at Cairo.''

The above analysis of the matter appears conclusive; but 17 years later there is given in the ''Journal of the Association of Engineering Societies'' for September, 1912, a paper on ''Levee System as a Means of Control'' by Arsène Perrilliat, which states as follows:

> ''North of Red River, on the west bank, the St. Francis Basin is not an outlet. It is a destructive reservoir. All water that enters it through crevasses fills it up, slackens the current velocity below the crevasses, causes bars, and then returns to the parent stream at Helena, enormously increasing the flood height at that point. This has been proven. On the east bank the Yazoo Basin, another enormous destructive reservoir which was used this year and caused the destruction of I know not how many millions of dollars of property, poured its water back in the river at Vicksburg and increased the flood height. The Tensas Basin on the west may again fill up as a reservoir, destroying itself—the very thing we don't want it to do—returning at Red River and adding to the flood height.''

Mr. Sellew states that in his opinion levees so located as to increase the carrying capacity of the main river will provide (by improving the hydraulic conditions) a more efficient channel than that which exists naturally and will go far toward neutralizing any ill-effects resulting from the loss of the reservoir capacity of the low marginal lands, which capacity, to be effective must be great enough to act as detention reservoirs during the passing of the flood crest. The combination of circumstances which will cause levees to raise flood-heights on alluvial streams is so infrequent of occurrence as to call in question the broad statement in Par. 65.

In Par. 76, it is stated that a sheet-pile cut-off beneath the levee, continued upward by concrete revetment to the river base of the embankment, ''would prevent saturation of the levee, seepage through the foundation, and erosion from wave-wash, and thus would eliminate the chief danger to the integrity of the system''.

Such treatment would prevent saturation of the levee and would protect it from waves; but the seepage through the foundation would be only slightly modified unless there existed an impervious stratum at moderate depth into which the piling was driven. Furthermore, this method provides no protection from caving banks, which constitute the real menace to levees along rivers flowing in alluvial formation.

In Par. 71 appears this question:

> ''Is it wise, as a rule, to provide for those extreme visitations which occur only once in a generation or so? Would it not be better to stop with provision for high floods, accepting the very rare deluges, with such emergency measures as might be practical at the time, and then foot the bill of damages?''

The answer to this question should be governed largely by the condition of the particular case under discussion. Many not fully developed communities are subject to frequent floods of ordinary volume, the control of which can be accomplished for an amount well within the reach of the resources of the area affected; while measures necessary to defend against extraordinary deluges occurring at wide intervals are beyond the ability of the district to finance. Such places must be content for the present with the minor development, leaving for future generations the consummation of the ultimate complete control. Mr Sellew.

There are other communities, however, already so thickly settled and so highly developed that they are fully justified in providing for the maximum flood which can ever come, because one such disaster would do more damage than the cost of averting it. Ask the question in Pittsburgh, Dayton, Erie, Los Angeles and many other communities similarly situated, and the sentiment no doubt will be almost unanimous for complete control, whatever the cost, since the cost can be covered by financial arrangements extended over a period which will insure a just distribution of the charge.

In discussing the Mississippi levees, in Par. 87, the author says:

> "Protection from undermining can be secured only by bank revetment, a very costly operation, or by retiring the levees beyond the danger zone, and this is objectionable from a reclamation standpoint."

Because of the wide meanders of the river and the prevalence of cut-offs, the determination of a safe zone for levee operations is impossible; and even if it could be fixed, the embankments would be abnormally high because of their extensive retirement along the rapidly down-sloping margins of the stream.

As the author points out, the interests of reclamation, the limiting of levees to reasonable heights, and favorable combination of hydraulic conditions to obtain the most effective channel, and the advisability of a regular alignment,—all demand that the levees be placed close to the bank of the river, thus confining the stream so that as far as practicable the low-water and high-water channels shall have a common axis. This is an ideal condition which never may be reached, but nevertheless it is the goal toward which all efforts should tend. Levees thus located can be protected by bank revetment and by that alone.

Mr. C. W. Harris* (by letter) states that General Chittenden in a paragraph on "Cut-offs" has opened a question that American writers have too often avoided—probably because conclusions on this topic can seldom be supported by any large amount of experimental data. Comment has been confined largely to opinion without fundamental analysis. It is hoped that this discussion may excite more effort to rationalize the method of attacking the important problem of cut-offs. **Mr. Harris.**

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Mr. Harris. Their effect on flood conditions has been the subject of very conflicting opinions. The majority of those discussing the subject tend decidedly toward the opinion that cut-offs increase flood height. Probably the long period of adjustment of river-bed, after a cut-off has been made, serves to obscure the real effect of the shorter permanent channel. The gradient is increased by a cut-off and two effects at once are apparent. The cross-section of the stream is reduced and its transporting power is increased. A small increase in velocity causes a much greater increase in transporting power, the tendency being for the bed to erode and the channel to be lowered—but this tendency is delayed by greater deposition below, and a temporary obstruction may form. This probably gives rise to the erroneous belief that cut-offs increase flood-height permanently. The delay in adjustment also gives opportunity for additional encroachments and occupation of the river channel to contribute to the increase of flood-height, thus strengthening this belief.

During the period of uniform flow at the crest of a flood wave, the direct effect of a cut-off is to relieve conditions in its vicinity. The lowering of the water surface because of the increased velocity also will cause a steeper gradient for some distance above and will extend relief upstream to a certain extent. The valley below practically will be unaffected. Any tendency of the gradient to flatten will be overcome immediately by the reduction of velocity and the channel will be governed by the features of the lower watercourse.

During the approach and recedence of a flood, the action may be somewhat more complex. Of course a flood wave once formed in a simple channel will reach a position below the cut-off more quickly because of the cut-off; there will be less time for flattening the flood wave and therefore its peak will be shorter and higher. This one cause alone will tend to increase the gage-height below the cut-off. However, there is at least one important counter-tendency. When rising, a stream has a rapidly increasing velocity and the flood is constantly overtaking the water in the channel below and combining with it. If the channel is shortened and reduced in cross-section by cut-offs, there is an appreciably smaller volume of water in the channel to be swept down to the valley below.

Cut-offs on the lower portion of a stream cannot help but lower flood waves upon its upper stretches; but the opposite cannot be said of floods in the lower valley if conditions are reversed. The effect of the floods in the lower valley is dependent largely upon the distribution of the rainfall producing the flood. If several streams contribute to the flood, the height in the lower valley will be greater or less, depending upon whether the shortened channel enables the water of one tributary to unite with or to avoid that of another. If the storm extends over the entire area at one time, floods from above may overtake those from below more quickly and cause an unfortunate combination. On the other hand, the period when such combinations can occur is shortened and the probability of their occurrence thereby diminished.

A storm moving downstream might have its flood increased by cut-offs. One moving up stream doubtless would be diminished. A storm moving at right angles to the watercourse also will in general have its effect diminished because of the greater facility for disposing of the water from one set of tributaries before the other set reaches its flood-height. Mr. Harris.

The problem of the effect of cut-offs on flood-heights is largely one of contributing causes; but so far as general statements are practicable, the effect of cut-offs seems to be to diminish flood-heights--a fact directly opposite to that commonly accepted by the engineering profession.

Mr. Chas. B. Burdick,* M. Am. Soc. C. E. (by letter), states that though very old elsewhere, flood-control is comparatively new in America; but that it is now and has been recently receiving very thorough study because of the exceptionally large floods in recent years, and more particularly because of the greatly increased habitation on the flood-plains of our rivers. Mr. Burdick.

Immediately following some of our recent and disastrous floods, it is perhaps natural that there should be more or less immature discussions as to remedies. The tendency has been shown by some to attempt application of a general remedy to all cases; but there probably is no field of engineering where local circumstances are more important than in measures for the relief from flood damages. The author's paper, therefore, does a very valuable service—not only by its brief statement of general principles, but particularly by the outline given of several of our important flood problems and a statement of the remedies that have seemed to be best fitted to each. These problems thus placed side by side emphasize in a striking way the great variety of conditions to be met and the diverse remedies that have seemed most applicable.

The author has classified flood works into two divisions, flood prevention and flood protection.

Depending upon circumstances, works falling in either class may be best adapted to a particular case. In general, however, flood prevention is the better adapted to extensive districts; and as the best remedy for a local situation, as relief from damage in a city, flood protection often will be found the best remedy.

Flood protection also must be resorted to everywhere in the absence of reservoir sites—for, as pointed out by the author, flood prevention is essentially a matter of water storage.

In the consideration of reservoirs for flood-control, it should be kept in mind that the time during a flood at which the storage is utilized has an important bearing upon its flood-prevention value. If the storage receptacle can be filled near the apex of the flood, much more is accomplished in flood prevention than if the basin be filled gradually. Artificial reservoirs or detention basins may be so designed and operated as to be available for "apex storage"; whereas the natural flood-plains of rivers

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Mr. Burdick. begin to fill early in the flood and may be nearly full before called upon to care for the maximum flow rate, and thus can mitigate the floods only to a much smaller degree.

A case in point is a recent investigation upon the Illinois River. The total drainage area upon this stream is 27,914 square miles, and the greatest measured flood (1904) is about 125,000 cubic feet per second. The stream has wide, flat bottoms for the lower 220 miles and the lands originally subjected to floods total 280,910 acres, of which 171,725 acres are already reclaimed by levees and probably nearly the entire area will be reclaimed within a few years.

In the flood of 1904, the total waters stored in the valley on land were equivalent to about 1.3 in. on the total watershed. Practically none of the land was then leveed.

It was estimated that should the flood of 1904 be repeated under the present leveed conditions of the river bottoms, the flood rate near the mouth of the river would be increased only about 5%, due to the reduction of flood-plain storage; also, that with all the bottom-lands reclaimed, the flood rate would be increased only about 10%. This rather unexpected result is accounted for by the fact that in an excessive flood, such as that of 1904, the valley practically is filled with water several days before the apex of the flood and the maximum flood rate occurs at a time when the gage-height is nearly stationary for several days before and after the apex.

The greater effect of apex storage is indicated by further figures. It was estimated that when the bottom-lands are fully reclaimed, if 65% of the area leveed were held in reserve and flooded only near the apex of the flood, with 850,000 acre-feet of water, the flood-flow rate thus could be reduced about 25%.

In the consideration of reservoirs or detention basins, it is noted that if materially reduced flood rates are to be expected, the storage must be large relatively to the drainage area. Thus during the flood of March, 1913, at Columbus, Ohio, the measurement of the flood-water in passing over the crest of a high dam was fairly accurate. It was estimated that the total rainfall on 1032 square miles was 9.34 in. in four days and that the water running away was about 8.68 in. in 11 days. The apex of the flood was reached on the second day, at which time the flow rate was equivalent to 2.8 in. in 24 hours.

The reservoirs suggested for the protection of Columbus would contain about 5½ in. upon the area tributary to them and about 2 in. upon the area above Columbus. The effect of much larger reservoirs is now being studied. For the protection of the Miami River Valley, it is understood that reservoir capacities of from 6 to 12 in. are being considered.

Compared to above storages, the storage in the flood-plains of the Ohio and Mississippi Rivers is small; thus, the 1000 billion cubic feet stored in the Ohio River Valley between Pittsburgh and Cairo is only slightly over 2 in. in depth upon the 201,000 square miles of watershed

above Cairo, and the 2000 billion cubic feet stored in the Mississippi River Valley between Cairo and the Gulf is only about 0.7 of an inch depth upon the 1,240,050 square miles above New Orleans. Mr. Burdick.

The author's reference in Sec. 57 to "Cut-offs", as a means of flood protection or drainage resorted to frequently, might tend to mislead in certain circumstances even though technically correct. However, there is in mind a situation where a flat valley, fed from hills, had an inadequate natural outlet so improved by channel straightening, that where the floods had stood naturally upon the land for several weeks, the water passed off through this enlarged outlet without flooding the lands. In this case nature provided a detention reservoir, which was destroyed through the channel straightening.

The local application of a "cut-off" may be immaterial in its effect upon the flow rate, not because the tendency to increase the flow rate is lacking, but because it is very minute. Thus in working out the flood protection of Columbus, Ohio, the channel improvements were considered and recommended for the protection of Columbus alone, the distinctive feature of the remedy being a "cut-off" as shown on Figure 7. This "cut-off" was not expected to deliver any larger flow rates below Columbus than formerly obtained, but it was expected to carry the formerly prevailing flood rates past the city on a lower hydraulic grade-line. It was not expected that the water-levels (and hence the flood-rates) below the city would be altered measurably. The tendency would be to increase the rate in some function of the water formerly stored upon the area to be protected during the flood. This area was very small relatively to the valley and could be shown to have a small effect upon the flood rate. However, if this remedy should be repeated again and again within the river valley, it is conceivable that an important effect upon flood rates might be obtained.

The subject of flood control would not be complete without some reference to the magnitude and frequency of floods in general. Those charged with the improvement of the Ohio and Mississippi Rivers are fortunate in that records are sufficiently lengthy to provide a fairly long back-sight that will serve as a safe guide for the future. However, much work is being projected at the present time upon streams having no such lengthy records, and where much less is known about past occurrences.

The late Emil Kuichling, M. Am. Soc. C. E., in the Report to the New York State Barge Canal in 1901, compiled a lengthy table of American and European flood flows. This table shows the effect of the size of watershed on the floods, also many other factors affecting them, and is a very valuable service to the engineering profession.

The engineering profession is indebted also to Weston E. Fuller, M. Am. Soc. C. E., for his admirable paper, No. 1293, in Vol. LXXVII of the Transactions of that Society. In that paper he presented the new idea of comparing the flow rates of great floods as ratios of the average flood rate on each of the respective streams. By this method of compari-

Mr. Burdick. son it is practicable to form a conception of the future ultimate flood that is in harmony with past experience. Whatever the uncertainties of forecasts may be (and they must be admitted to be uncertain), they are required for intelligent decisions as to the advisable extent of protection in various circumstances. Mr. Fuller's paper, with its wealth of accompanying data, is well worth the study of anyone engaged in works of flood control; and it is believed that he is entitled to credit for a suggestion that will permit of more accurate forecasts in most circumstances than before were possible.

Works projected for flood control must be practicable financially, or the design is of little use. Where great loss of life is involved, the ultimate should be provided against if at all practicable; but there are many cases where the extent of protection is a financial consideration, and in such cases the best information procurable as to the magnitude and frequency of floods is required for the proper design of protective works.

Mr. Davis. **Mr. A. P. Davis,*** M. Am. Soc. C. E. (by letter), states that the first part of General Chittenden's paper dealing with the general principles of the origin and control of floods is a very valuable summary of principles and makes short work of several popular fallacies regarding flood control and shows the limitations of some other theories. The second part, discussing nine of the most important flood problems of the United States, shows in a brief space the result of a large amount of research; and coming from so high an authority is a very valuable contribution to the literature of flood control, the more so for its being in such condensed form.

Paragraphs 47 and 48 show clearly the relatively local effect of reservoirs on flood control. This may be illustrated further by reference to a number of projects of the United States Reclamation Service, where reservoirs built primarily for irrigation afford important incidental benefits in reducing flood discharges—which benefits, however, are mainly local in their influence.

The Pathfinder Dam, on the North Platte River in Wyoming, forms a reservoir of 1,100,000 acre-feet capacity; this is less than the mean annual discharge at this point, but greater than the flow in minimum years. Shortly after this reservoir was constructed, the North Platte basin was visited by a flood having a maximum discharge nearly twice as great as that of any previous recorded flood. The flood flow occurring above the reservoir was impounded therein with only a moderate discharge flowing through the gates, yet the discharge below this reservoir was about as great as for any previous flood and did considerable damage by overflowing the valley below. Had it not been for the reservoir, the flood wave would have been nearly twice as large and greatly prolonged, and it is believed would have swept away nearly all of the bridges over the North Platte River, besides inundating large areas of agricultural

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land and many towns. It is believed that if this flood had been uncontrolled, the damage from it would have been greater than the entire cost of the reservoir. The Pathfinder Reservoir, without any special attention to the flood-control element, is bound at all times to exert a powerful regulative effect upon the flood-discharges of the North Platte River. Mr. Davis.

The Elephant Butte Reservoir on the Rio Grande has been constructed with a capacity of about 2,700,000 acre-feet and is designed primarily for irrigation. However, it will necessarily have a great influence upon flood-control in the valley below, where in past inundations the river has caused great damage to railroads and to riparian property. In this case the interests of the project demand that the flood discharge be limited to the capacity of the river channel, which is about 8000 cubic feet per second; but there is a possibility, at rare intervals, that a flood of nearly this magnitude may be brought into the stream below the reservoir. Therefore, plans have been made to provide for the discharge of flood flow from a full reservoir in such a manner as to prevent the discharge of more than 8000 cubic feet per second; and a controllable spillway is provided, by which this discharge can be shut off temporarily in case of a phenomenal flood in the valley below. By this provision it is expected to control the flood discharge at all times, to within about one quarter of the maximum natural flood flow.

The Salt River Reservoir also will have an important effect upon the height of flood waves in the river below and will prevent considerable damage which otherwise would be caused by floods.

Other reservoirs constructed for irrigation by the United States Reclamation Service will have more or less influence upon flood flow, but in all cases the influence is relatively local. The Pathfinder Reservoir, although important with regard to the flood-flow protection of the Platte Valley itself, will have no appreciable effect upon the destructive floods of the Missouri and Mississippi Rivers, since these floods occur mainly as the result of rainfall in the humid region, and are affected only to an insignificant extent (if at all) by the flood discharge from the upper Platte Valley—which is not only relatively small in amount, but seldom, if ever, coincides with the flood wave from the humid region.

Mr. Courtenay.

Mr. W. H. Courtenay,* M. Am. Soc. C. E. (by letter), in commenting on Section X of General Chittenden's paper "The Railroad Problem", states that his experience has been that more damage in the aggregate has been done to railroad roadbeds and track by sudden, violent rainstorms, often local or covering no very great extent of territory, than by submergence of track by backwaters from great rivers like the Ohio.

During the great and general storm of March, 1913, about 30 miles of the track of the Louisville & Nashville Railroad Company were submerged in Butler, Conecuh and Escambia Counties, Alabama, and several miles of its track in northwestern Florida, the water attaining a depth of 10 feet or more above the track in places where the track had never

*Chief Engineer, Louisville & Nashville Railroad Company, Louisville, Ky.

Mr. Courtenay. been known to be flooded before, although the railroad had been constructed for more than 50 years.

However, the greatest damage to the railroad was not done where the track was submerged, but by the tearing out of a number of culverts which theretofore had been of ample capacity—these culverts being under fills 25 to 30 feet high and their failure resulting in the cutting out of large sections of these embankments. In other words, the maximum damage to the railroad was on an ascent to a ridge not submerged by the flood.

The backwaters of a great river like the Ohio may submerge railroad tracks to a considerable depth without doing much physical damage, for usually the water rises so slowly that there is sufficient time for the height to equalize on both sides of the embankments through culverts and bridges crossing tributaries of the river.

Trains prudently may be moved slowly over submerged tracks in such situations, even when the depth of water above the rail is 3 feet, provided care is taken in advance of the passage of trains to see that the roadbed is not eroded. Mr. Courtenay has ridden through such backwater in a number of places and on different occasions. So far as his experience goes, more damage to railroad structures has been done by tributaries of the Ohio River than by the Ohio itself; for in any situation where the railroad is not parallel or approximately parallel to the current and where the water attains much greater height on one side of the roadbed than on the other, the damage begins when the water commences to flow over the top of the railroad, and under such circumstances, as a rule, the greater the height of the embankment the greater the damage.

As indicated by the Author, it is impracticable to guard against sudden freshets of great violence, and these occur not only in mountainous sections but in other sections and are particularly frequent in the Gulf States. During July, 1896, a storm of somewhat limited area in the valley of Benson Creek, Kentucky, did a vast amount of damage to the railroad built in that valley, destroying several bridges and washing out large parts of the railroad embankment.

At the time of this occurrence, the railroad had been built nearly 70 years. No such flood has ever been known in the creek either before or since 1896, so it is manifest that it would have been false economy in the construction of the railroad to attempt to provide against a storm of that character.

To the writer's knowledge, similar local floods have occurred in Illinois and in various parts of Kentucky, Tennessee, Alabama and Mississippi, occurring but once in each stream so far as known, but doing considerable damage. Construction such as would permit the passage of such floods without damage to the railroad structures would not be economically justifiable.

Whether the generally very great cost of such construction as would be required to put railroads without doubt above or beyond the reach of

floods will be justified depends upon the frequency of the floods and the amount of traffic carried by the railroad. Mr. Courtenay.

Mr. J. B. Lippincott,* M. Am. Soc. C. E. (by letter), states that from the court records of Los Angeles County in a flood-damage suit, entitled "Daneri vs. the Southern California Railway Co.", it has been established fairly well that during the last 50 years destructive floods occurred at intervals of from 3 to 4 years. The floods of January and February, 1914, were of unusual violence, and of particular prominence because of the long cycle of dry years preceding them; but a careful study of flood-marks, and of rough measurements made previously, indicates that the flood of 1889 probably was 60 to 70% greater in volume in both the Los Angeles and San Gabriel Rivers than the floods of 1914. Mr. Lippincott.

In 1893 an effort was made to secure concerted action for the control of the San Gabriel River above El Monte, and in 1898 a commission was appointed by the county to investigate and report upon a suitable channel-control of that stream. This was followed in 1913 by a special study made by Mr. Frank Olmsted, and by the appointment in the spring of 1914 of a Flood-Control Commission consisting of the following engineers: H. Hawgood, C. T. Leeds, J. B. Lippincott, F. H. Olmsted, Mems. Am. Soc. C. E. and Mr. J. W. Reagan. This commission made a study extending over some 15 months and filed a report at the beginning of August, 1915.

The flood problems of southern California are peculiar to that region. The physical features of this region consist of a main coast range composed of crystalline rocks, the crest of which rises to elevations from 4000 to 10,000 feet above sea-level. In the regions near Santa Barbara, the foot of the slopes of this range practically is washed by the sea, but in the eastern end of the San Bernardino Valley recedes therefrom to distances of 50 miles or more. On the ocean side of the range the slope varies from 200 to 300 feet to the mile in the main mountain drainage-lines, and in the smaller ones from 700 to 1400 feet to the mile. In the Los Angeles district there is a secondary range of sedimentary rocks that occurs approximately midway between the shore-line and the main range. The drainage from the main range breaks through this secondary range in broad canyons at the city of Los Angeles on the Los Angeles River and near El Monte on the San Gabriel River. The secondary range develops a series of broad valleys lying between the mountains, and below the secondary range is a broad coastal plain.

The San Gabriel River, with its 222 square miles of high mountain drainage is the largest stream in Los Angeles County. Speaking in general terms, it has been found that the rainfall in this county is in the neighborhood of 14 inches per year at sea-level; and that on the ocean side of the range the precipitation increases up to 4000 feet elevation at the rate of six tenths of an inch additional rain per annum for each 100 feet rise in elevation. Above 4000 feet elevation, the rate of increase

* Cons. Engr., Los Angeles, Calif.

Mr. Lippincott. is approximately four tenths of an inch per year per 100 feet rise. Therefore there are extensive precipitous mountain drainage areas with heavy precipitation, nearly all in the form of rain, and concentrated in two or three of the winter months. This produces violent floods of short duration, followed by low stream-flow during the summer. Careful measurements of flood marks and other determinations indicate that the floods of 1914 ranged from 115 sec-ft. per square mile on the larger mountain watersheds, to four times that amount in the smaller precipitous basins, the maximum indicated flow being from Sunland Wash, containing 2.7 square miles of foothills and 3.9 square miles of mountains, which had been denuded by fire during the preceding summer and which discharged water at the indicated rate of 712 sec-ft. per square mile. In this discussion, 50 California miner's inches are equivalent to a second-foot.

The above-mentioned flood volumes are surprisingly great even to engineers who for years have practiced on the Pacific Coast.

As may be expected, these violent floods rushing out of the mountain canyons carry with them enormous quantities of debris, which they deposit in fan-like masses called delta cones, the apexes of which are situated at the mouths of the canyons. The great valleys intermediate between the foothills and the main range by this process have been filled up to depths that are known from well-borings to be greater than 1000 feet. The coarser material is deposited near the mountains and the finer further down in the valley, the coastal plain being built up of alluvial silts which produced fine agricultural soils but which are unstable against the erosive attacks of water.

Through ages past, the wandering floods have been partly absorbed and have created enormous bodies of underground water extending from the main range to the sea. In the detrital valleys these underground waters slope toward the outlet of the secondary range and artesian pressures are not developed. The waters escaping underground from the upper valleys percolate beneath the finer soils of the coastal plain and in their progress to the sea are interrupted by a minor geological fold near the sea and artesian conditions are created through a broad coastal area. These underground waters are the main source of supply for southern California, and from two thirds to three quarters of the entire area irrigated in southern California are served therefrom.

The gradients of the streams are precipitous in the mountains and about one percent across the intermediate valleys; but through the coastal plain they become as flat as 3 feet to the mile. This radical variation in the gradients naturally causes progressive deposition of silt, with an accompanying continuous building-up of the present storm channel and the shifting of the stream to new localities. In the early days, when the country was used for grazing purposes and subsequently when agriculturally developed, these meandering streams probably did as much good as damage in the lowlands, in that they spread rich humus from the mountains over the plains. However, as urban and suburban conditions

have developed, these streams have become destructive and intolerable. The direct flood damages in 1914 have been estimated at $10,000,000, exclusive of the deposition of some 5,000,000 cubic yards of silt in the harbor of Los Angeles. Mr. Lippincott.

On most rivers in the mountainous regions of the West, the flood stage, slowly rising through May, culminating in June, and subsiding in July, is coincident with a period of melting snow; but in southern California, violent winter rains occur and are followed promptly by violent floods.

In a community such as the city of Los Angeles, where approximately $50,000 per second-foot of flow has been expended in obtaining a new water supply, and where the available water is the limit and the measure of the development of the community, it follows that in flood studies, plans for conservation should receive first attention.

It is very popular to talk about preventing the destructive rushes of the floods through the highly improved valleys and the saving of them for beneficial use. The scientist claiming to be able to do this naturally attracts the public; and the following of false hopes leads to disappointment and to substantial injury, in that it delays beneficial work and discourages the public from making further efforts along safe lines.

It is claimed that floods should be prevented by the forestation of the mountain slopes. In the United States there is little exact scientific data indicating the real effect of forests on flood discharges. Prof. J. W. Toumey made certain measurements in the San Bernardino Mountains in 1899 for the Bureau of Forestry and published a paper entitled "The Relation of Forest to Streamflow". This is referred to on page 24 of Water-Supply Paper No. 142, U. S. Geological Survey. Four small drainage basins were studied, with the following results:

Precipitation and Run-off During December, 1899.

Condition as to cover	Area of Catchment Basin Sq. mi.	Precipitation Inches	Run-off per Sq. mi. Acre-ft.	Run-off in percentage of precipitation Percent
Forested	0.70	19+	36—	3
do	1.05	19+	73+	6
do	1.47	19+	70—	6
Non-forested	.53	13—	312+	40

Rainfall and Run-off During January, February and March, 1900.

Condition as to cover	Area of Catchment Basin Sq. mi.	Precipitation Inches	Run-off per Sq. mi. Acre-ft.	Run-off in percentage of precipitation Percent
Forested	0.70	24	452+	35
do	1.05	24	428+	33
do	1.47	24	557+	43
Non-forested	.53	16	828+	95

Mr. Lippincott.

Rapidity of Decrease in Run-off After Close of Rainy Season.

Condition as to cover	Area of catchment basin Sq. mi.	Precipitation Inches	April run-off per Sq. mi. Acre-ft.	May run-off per Sq. mi. Acre-ft.	June run-off per Sq. mi. Acre-ft.
Forested	0.70	1.6	153—	66—	25—
do	1.05	1.6	146—	70—	30—
do	1.47	1.6	166+	74—	30+
Non-forested	.53	1	56+	2—	0

Those experiments were not extended enough to be conclusive. They indicate substantially greater flood flows from the non-forested basins and substantially greater summer flows from the forested basins.

The writer agrees with General Chittenden's statement that the effect of forestation on maximum flood flows is not substantial. However, the effect of the summer flow of streams from forest or brush cover is substantial and of great value. The mountains of southern California (even in the Forest Reserve) are covered with brush rather than with large trees. The brush cover probably is as effective for purposes of stream regulation as the forest, and for the prevention of erosion it is more effective.

A positive benefit derived from forestation is the prevention of erosion. The prevention of the deposition of from a few inches to three or four feet of sand and gravel over highly improved country places and concrete roads is sufficient justification for efforts to preserve the vegetation on our mountain sides. This can be accomplished best by the prevention of forest fires and by the building of roads, trails and fire-breaks.

It may be practicable to re-forest the crest of our Coast Range and a portion of its northern slopes, but it has been established that it is not economically feasible to re-forest the southern slopes of our southern California mountains below elevations 3000 to 4000 feet above sea. Out of 40,000 forest trees planted in the Cahuenga foothills by Mr. Lippincott, it is doubtful if 50 trees are now alive.

The U. S. Bureau of Forestry probably can be induced to undertake an extended and intensive experiment in southern California to determine the effect of forest and brush cover on stream-flow, and it is to be hoped that the public authorities will cooperate with them in this work. Such a study is being made now in the mountains of Colorado.

Another popular theory of flood prevention favors the building of reservoirs to impound flood waters. The Board of Engineers for the Flood Control of Los Angeles County surveyed everything that had the appearance of being a reasonable reservoir site throughout that region. Only one, the Arroyo Seco, at Devil's Gate, was found which was considered would have substantial benefit. On the assumption that 20 percent of the capacity of that reservoir would be used for the retention of the available flood waters and the other 80 percent for flood regulation, a detailed study of flood conditions for the year 1914 indicated that the maximum flood wave passing the dam would have been reduced only

Mr. Lippincott.

from 11,000 to 9,000 cubic feet per second through the utilization of that reservoir. Such utilization would control the floods from 30½ square miles of high drainage-basin which destructively discharge through the city of Los Angeles. With a dam of 90 feet maximum height, the capacity of the reservoir would be 4600 acre-feet. The impounded water would be used for the domestic supply of Pasadena, South Pasadena and Alhambra.

However, there are places in other regions where the construction of reservoirs for the impounding of flood-waters is of advantage for flood-control, such as the Roosevelt Dam on Salt River, Arizona. Such places are in general scarce, however; though in considering them, the incidental advantages of such impounded waters for irrigation and power should not be overlooked.

Sometimes the winter flood flow of streams may be conserved beneficially in the great underground gravel reservoirs by a process of spreading the floods in thin sheets over the coarse gravels and thus conserving the winter flood flow for future summer irrigation. In the San Bernardino Valley, California, many acre-feet of water are thus conserved in gravel reservoirs at a cost of 14c per acre-foot. When extracted by pumps in the summer, this water is worth $6.00 per acre-foot for irrigation. In certain districts where the ground-water levels had fallen over 100 feet, flowing wells have been restored by the spreading of these winter flood waters.

The principle is recommended of publicly acquiring large areas of coarse detrital deposits near the mouths of mountain canyons, into which the winter flows of streams can be discharged for conservation. This practice has its limitations, however. When great floods of 10,000 to 20,000 cubic feet per second occur, flowing on steep gradients with velocities of 10 to 15 feet per second, it is not feasible to spread them over gravel beds. Such great flows usually are muddy, and it is good practice to wait until the stream has clarified before it is spread, because otherwise filter-beds become clogged. While the spreading process will conserve a natural resource of great value, it will not diminish the great floods substantially.

In some European localities, and in Japan, the practice has developed of building a multitude of small rock and brush dams but 5 to 10 feet in height and with drainage areas of but a few acres. The small basins thus formed fill with gravel, reduce the grade of the stream by a step process, and hold back some percolating water and make it available for summer use. In Los Angeles County, during the past winter, an experiment was made on a small scale of such basins, and the results appear encouraging. For future guidance, it has been recommended that these experiments be carried out on a more elaborate scale. There is not sufficient information at hand at present to justify a statement that such low dams would be broadly beneficial either for reducing maximum flood flows or for sustaining summer flows. This subject is worthy of careful

Mr. Lippincott. study, and information is desired from engineers who have had experience along this line.

The control of the great floods of southern California will have to be effected by the construction of levees. The levee problem is one beset with difficulties, because of the unstable character of the soil, the high velocities of the streams, and the deposition of silt with the accompanying flattening of the grade. These levees will have to be protected by substantial foot-walls to prevent undercutting, and by riprapping their sides or facing them with concrete laid in flexible blocks.

It is essential that the channels so constructed should be kept free from trees and brush. Thickets in stream channels become effective diversion weirs by deposition; and, conversely, when they are cleared, the stream will maintain itself by erosion. When Los Angeles County builds its flood-control works (as it undoubtedly will), it certainly must follow its construction by a policy of energetic maintenance. In times of great flood it must be possible to call quickly for extensive help, approaching the condition of the Corve of Egypt or the fire-fighting policy of the U. S. Forest Service.

Public policy justifies fully the substantial appropriation of public funds (from the national, state or county funds) for flood-protection works in southern California. As a matter of plain justice, those who are specifically aided should contribute principally to the cost of those works, in accordance with the benefits received from them.

Mr. Matthes. **Mr. Gerard H. Matthes,*** M. Am. Soc. C. E. (by letter), stated that the author has succeeded in summarizing the principal features of a large and complex subject briefly and in a masterly manner. He is to be congratulated especially on the excellent presentation of the commercial aspects of the subject given in Section IX, entitled "Complexities of the Problem—Physical and Financial". This phase, so often overlooked by theorists, cannot be over-emphasized.

Flood control is not achieved by applying theories or formulae; it is essentially a question of meeting existing conditions. If rivers could be regulated and protection against floods provided before valleys are settled, the "levees only" theorist and the reservoir extremist would have a luxurious field in which to revel. Unfortunately for both, history teaches that repeated flood damages to valuable property must occur before flood-control measures are likely to be initiated. Not until Rome had been devastated time and again by the floods of the Tiber River was a Commission of Roman Senators appointed, in the year 53 B. C., to regulate that river against floods. Since that time, the civilized world has seen but little change in dealing with such problems.

In many a valley in the United States, agricultural lands, hamlets and villages are being swept periodically by flood waters. Yet it would not be warranted to burden such districts with costly flood-control works, any more than to provide them with up-to-date fire departments and

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water-supply systems for protection against fire losses. Not until the hamlets and towns have grown into cities and the valley has become crowded with factories, railroads, bridges and other valuable improvements subject to damage by flood water, will there be enough taxable property at stake to bear the cost of comprehensive measures. At least this is the condition now in the United States. In Europe, under more paternal forms of government, agricultural as well as industrial districts have been protected from floods; but in the United States, State and Federal aid are not readily invoked and protection must be financed largely through taxation and subscription. Usually individual towns can resort only to local protective works. When a crying need arises for the comprehensive protection of a valley against floods, it generally is found that a very large number of interests must cooperate in order to finance such an undertaking; and what would have been a simple engineering matter when the valley was still young in settlement, has developed into a complex economic problem. Not unlikely it will be found that cities have grown up in the bottoms of the best reservoir sites, and that railroad grades are such as to impose limits to the practicable heights of levees. In the past, inability to secure harmonious cooperation on the part of the diverse public and private interests affected has been the source of failure of many promising and much-needed projects. Success in securing such cooperation depends almost wholly on the persistent activity and able leadership of public-spirited men of the highest type and upon the formulating of clean-cut business propositions. Only those directly benefited by the construction of extensive flood-control works should be assessed with the cost thereof; and sound business principles require that the individual benefits to be derived, whatever their form may be, shall be manifest and be commensurate with the assessed cost. Mr. Matthes.

It is regrettable that General Chittenden's paper relates exclusively to flood problems of the larger streams. Attention should be called to the fact that the lesser streams (those draining areas of 400 to 100 square miles and less) present equally serious problems, and that in many localities such problems are not receiving the attention which they deserve. Maximum flood discharges on such lesser streams are brought about by cloudbursts or by other forms of excessive precipitation, and usually occur during the summer and fall months. Since such storms rarely cover more than fifty square miles of territory, the excessive run-off caused by them does not affect the larger streams. The damages inflicted on the smaller streams are very often great, however, comprising the destruction of dams, mills, bridges, railroad embankments, and highways, and the ravaging of crops. The annual damage from this source in the United States is difficult to estimate, but on the whole has been much underrated. Mr. Matthes estimates that in the state of Pennsylvania alone such damage averages in the neighborhood of a million dollars annually. The fact that the great majority of streams are of the lesser type and that on these are situated or will be built hereafter the great majority of struc-

Mr. Matthes. tures, renders the subject one of considerable importance to the engineering profession. The reasons why it has claimed comparatively little attention in the past are: (a) lack of authoritative data pertaining to frequency of recurrence and to intensity of maximum rates of run-off from small areas; (b) lack of publicity, such floods being principally of local interest; and (c) the prevailing impression that such floods are rare events—attributable to man's inability to recollect distinctly occurrences of 15 or 20 years before.

There is a wide-spread but erroneous belief that floods caused by cloudbursts (by excessive precipitation over small areas and of short duration) are of such rare occurrence that it would be unwise usually to design structures and channel capacities large enough to accommodate them; in short, that such floods belong in the category of "extreme visitations which occur only once in a generation" mentioned in Par. 71 of the author's paper. The facts do not justify such a belief. From data collected by Mr. Matthes, it appears that floods of this type recur on the lesser streams of the eastern United States with a frequency of from 5 to 6 times in a century; and that this periodicity probably obtains over a large part of the United States, with a tendency to decrease in the northern latitudes.

The most satisfactory records are found in such of the older towns as are located on small streams. A good instance is the record for Baltimore, Maryland, which extends back to October 5, 1786, when the little stream crossing the city, known as Jones Falls, rose to an extreme stage, destroying a church, bridges and other property and many lives. In the century which followed, Baltimore suffered from similar disasters eight distinct times; and only recently has Jones Falls been provided with a capacious underground channel. Another long record is that of Codorus Creek at York, Pennsylvania, where five destructive cloudburst floods have occurred in the course of a century. For over a year past the city of York has been devising ways and means for protecting itself against future damage from this cause. The city of Erie, Pennsylvania, was devastated by cloudburst floods on Mill Creek successively on Sept. 13, 1878, May 17, 1893, and August 3, 1915; and is now planning to make ample room on the creek for cloudburst floods. The Erie rainfalls on these occasions were by no means exceptional, being respectively 5.11, 4.71 and 5.77 inches—most of which fell in a few hours' time in each instance. In contrast is the case of Harrisburg, Pennsylvania, where 4.38 inches of rain fell during 4½ hours on August 21, 1915, without causing any damage along Paxton Creek, which traverses the city. In 1908, at an expense of about $115,000, Harrisburg rid itself from the ever-recurring overflows of Paxton Creek by building simple, yet effective, flood-prevention works a few miles north of the city. Denver, Colorado, has been flooded by Cherry Creek time and again, and has built costly channel improvements, but has not yet solved the problem completely. Turkey Creek in Kansas City, Missouri, and Roaring Brook in Scranton, Penn-

sylvania, are typical of a long list of small streams causing periodic havoc in cities which have failed to provide for such emergencies. Rural districts abound in evidences of this kind, but the records cannot be collected as easily as in the cities. An instance of an entire town being destroyed by a cloudburst is that of Heppner, Oregon, on June 14, 1903, destroyed by a flood in Willow Creek. The world gasped at the horror and many people believed then (and some do yet) that it was an act of Providence, perhaps never to be repeated. Fifteen years previously a very similar flood had occurred in Willow Creek, only Heppner was not then in existence and the event attracted little notice. Mr. Matthes.

Many more instances of such flood periodicity could be cited. However, the foregoing instances serve to illustrate that, contrary to popular belief, cloudburst floods on the lesser streams are not extraordinary occurrences and to indicate that provision should be made for them in the design of structures, wherever reasonably warranted.

In Par. 161 reference is made to the use, by the Water Supply Commission of Pennsylvania, of a special formula for computing flowage space under bridges and through culverts. It should be stated, however, that the Commission places little reliance upon any of the many empirical formulae for computing maximum run-off. It recognizes the fact that the run-off conditions for any one stream at a given locality must be regarded as special for that stream and locality; also that the character of the structure to be designed always should be taken into account. For instance, it would not be good engineering to make provision for the same maximum flow at a through-truss highway bridge with low approaches, at a deck-girder railroad bridge, at an open trestle, at a culvert under a high embankment, and at a spillway for an earthen dam—even though all of these structures were located on the same stream and not far distant from each other. The factors which enter into such flowage-space considerations are so many that no formula can be devised which will even approximate all of the requirements. To make intelligent estimates for proportioning the many hundreds of structures on which it has to pass annually, the Water Supply Commission of Pennsylvania relies principally on its extensive collection of stream-flow statistics and flood records (probably the most complete collection of its kind), and also on its intimate knowledge of the characteristics of the individual streams of the State. Its methods of handling such problems are described in the annual report of the Commission for 1914.

Through special act of the legislature, Pennsylvania undertook in 1913 an inventory of its water resources; and as a result of this work is today better informed than most states on the subject of floods. It is carrying on systematic stream-gaging operations at more than one hundred gaging stations, and in 1913 inaugurated a system of flood forecasting on the Susquehanna River and its tributaries. The predictions are based principally on the "gage-relations" method described by the author in his Par. 32 and to some extent on compilations of the discharge of tribu-

Mr. Matthes. taries. For forecasting flood heights at stations along a large river below the confluence of two or more important tributaries, certain empirical formulae applied to the stages at points above the confluence have been found to give the best results. The system has yielded satisfactory results both as to accuracy and timeliness. Its usefulness in preventing flood damage is now well recognized, and its comparatively small cost to the State appears to be entirely justified.

Through the courtesy of the Water Supply Commission of Pennsylvania, Mr. Matthes is enabled to give here a few of the facts which have been established by its investigations and which are of special interest in this connection:

(a) Extraordinary floods are not now any more frequent or more severe than they were formerly. Incomplete statistics concerning early floods and the rapid rate of increase of flood damage in the State are the principal reasons for the popular misconception that floods are increasing both in intensity and frequency.

(b) The increasing damage resulting from floods is traceable directly to the ever increasing amount of damageable property which is being placed by civilized man in the paths of flood waters.

(c) Extraordinary floods are more frequent than is supposed commonly, occurring on the large rivers twice and sometimes oftener in a century and on the lesser streams as often as six times in a century.

(d) The majority of floods occur during the winter and spring seasons, but in most instances the greatest floods of record were caused by summer or fall storms. Those on the lesser streams were caused by cloudbursts covering comparatively small areas; while those on the larger streams were caused by storms of great extent and severity, usually lasting two days and yielding 8 to 12 inches of rainfall. This rule does not apply to drainage basins so shaped as to preclude the possibility of being covered in their entirety by one such storm. The headwaters of the Ohio River are an exception of this kind.

Storms of the type referred to (of great extent and severity) are rare occurrences. Some well known instances are as follows:

The storm of October 9-10, 1908, over parts of New York, New Jersey and Pennsylvania, which caused the greatest known floods on the Delaware, Passaic and Lackawanna Rivers;

The storm of May 31-June 1, 1889, over central Pennsylvania and a portion of New York, which caused the greatest recorded floods on the Susquehanna River, its West Branch and the Juniata River;

The storm of August 11, 1888, in West Virginia and southwestern Pennsylvania, which caused the greatest flood on the Monongahela River and some of its tributaries;

The storm of October 3-4, 1869, in the New England States is another typical storm of this kind.

Mr. Matthes' study of the subject convinces him that in those parts of the United States where other forms of vegetation are plentiful, the presence or absence of forested areas has no appreciable effect on the maximum rates of run-off. In this connection, it is of interest to know that the greatest flood on the Ohio River at Pittsburgh, of which reliable record is preserved, took place on March 9, 1763, when the virgin forest was still intact. At Pittsburgh that flood exceeded the famous flood of March 15, 1907, by 2½ feet. Some of the flashiest of the Ohio River tributaries—notably the Clarion, the Youghiogheny and the Cheat Rivers, draining 1400 to 1800 square miles each—rise in some of the most densely forested areas in Pennsylvania and West Virginia. The flashiness of these streams is directly attributable to the configuration of their drainage basins—and it is thus shown that high rates of run-off are due much more to the influence of the topography and the geology of the drainage basins than to the character of their vegetation. Mr. Matthes.

Mr. Arthur E. Morgan,* M. Am. Soc. C. E. (by letter), states that General Chittenden's paper is the most orderly and condensed presentation of the subject that he has seen. It is the more valuable in that it holds to the spirit he expresses: "The flood engineer must be bound to no system, but must determine, with judicious insight, the treatment which best suits the particular case". The tendency to generalize and to hold to certain systems as applicable in all or most cases has reduced greatly the value of the flood-prevention discussions and studies of the United States. Mr. Morgan.

The usual object in discussing a paper of this kind is to indicate differences of opinion from the author. He feels that a discussion limited to this field would be very short, as there are very few statements made in the paper which arouse criticism.

It is perhaps possible that General Chittenden has over-estimated the relative importance of levees as a means of flood prevention. His statement "that they will continue to be the chief means of flood relief admits of no doubt" is perhaps true if applied only to large streams. However, taking the entire field of flood prevention, it is believed that the improvement of channels by widening, deepening and straightening, and by the construction of artificial channels, is by far the most general method of flood prevention—being applicable in more individual cases than any other method, and probably for the reclamation of a greater territory. The amount of such work which has been done already in the United States is not realized by those who have not given the matter particular attention. It is found that in the control of small streams, with drainage areas up to a few hundred square miles, it usually occurs that channel improvement is a cheaper means of flood prevention than levee construction. For instance, in the streams of West Tennessee it is found that channel improvement is preferable for streams draining hill areas of 50 to 150 square miles; while for larger areas, levees are more economical up to a certain point, beyond which the flood-way or by-pass

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Mr. Morgan. system is more efficient. The disadvantage of levee construction over that of channel improvement is so definite that wherever the cost of protection is equal, channel improvement by widening, deepening and straightening is preferable. As values increase and the interests at stake become greater, channel improvement will be carried to greater lengths and will be used on larger and larger channels for supplanting levees. However, the fact remains that for channels of any considerable size, draining more than a few hundred square miles, channel improvement usually is impracticable.

In the author's discussion on the effect of levees upon raising the bed of a river, there seems to be a slight oversight. In Par. 66 is found the statement "it is difficult to assign a reason for such a conclusion (that the construction of levees causes a raising of the bed of the channel). Theory would lead in the opposite direction. Surveys on the Mississippi do not show any evidence of such a tendency". In Par. 85, under the discussion of sediment in the Mississippi River, is found the statement, "Bank caving does not increase this quantity (sediment) for otherwise the bottoms would be wearing away, whereas the reverse is actually the case".

In the discussion of levees, the author very truly says, "Levees thus increase their own height and the full extent of this increase seems never to be anticipated, or at least admitted, by those responsible for the development of great levee systems". It seems very strange that this should be the case, as it undoubtedly is. In all parts of the country we find sewer systems designed and built without any definite effort to determine the extent to which the contraction of the flood channel will raise the flood-plane. Without such determinations being made as closely as practicable, the design of levee systems can be scarcely more than guess work. It is no more difficult to determine the extent to which the construction of the levees will raise a flood-plane than it is to determine beforehand the increase in capacity of an improved natural channel.

The author states very pertinently, "While floods on the lower (Mississippi) river are results of fortuitous combinations, and the records reveal no higher results of such combinations than something slightly in excess of two million cubic feet per second, there is no reason *a priori* to suppose that such may not occur". The great floods on the Mississippi of 1912 and 1913, the two largest in the history of the river, resulted from rainfalls in quite different parts of the watershed. Other rainfalls, occurring at different times of the year, have exceeded materially the rainfalls of either of these storms. The laws of chance would seem to indicate it is only a matter of time until a combination of heavy rainfalls in different parts of the watershed will create a flood very much in excess of any of those which have been recorded since the substantial beginning of the levee system in 1883. Any public policy which ignores such a possibility and builds only in view of the greatest recent flood, may require material revision in the future.

Mr. Morgan.

Under the heading of "Method of Financing Flood Prevention Works on the Mississippi River" the author states, "Considering the vast benefits directly accruing to lands protected, it would seem that except in special cases of narrow bottoms, such lands should bear at least half the original cost, and the same proportion of the annual cost of maintenance". This is a phase of the problem which has not been given adequate consideration in this country. The Nation's attention to the needs of the lower Mississippi has been brought about by representatives of the lower valley, not anxious to increase their own burdens and usually in an effort to secure Government appropriations. The fact is, that by far the larger part of the overflowed lands of the lower Mississippi are held in large tracts by great corporations, or by planters owning thousands of acres. Some of these holdings are a hundred thousand acres or more in extent, and comparatively few small tracts are held in such size as would constitute individual farms for persons of moderate means. For the most part, these lands when reclaimed will be sold by the present owners to others who will make actual use of them. If the national Government pays the cost of their reclamation, the effect will be simply an addition to the selling price of the land, and in fact the Government will be making gifts to the present owners of these great tracts.

Before a permanent program of Government assistance is settled upon, a plan of coöperation should be established, which may be stated as follows:

The relation of the Government expenditures to the local expenditures should be, as nearly as can be determined, in the same proportion that the interest of the people as a whole bears to the interests of the owners of the land reclaimed. With this principle definitely accepted and established, its working out in individual cases will be a matter of investigation and judgment. This relation will vary greatly in different cases. In some, by far the greater part of the benefit will accrue to the private owners; in others, to local subdivisions of the Government; and in others, the interests of the people as a whole will predominate and the private benefits will be comparatively small. Nothing would go further to establish flood protection on a firm and rational basis in the United States than the adoption of this principle. In its application there is no need for making any distinction between the Mississippi River and other streams. The claims that the Mississippi is "the Nation's drainage ditch" and that floods on the lower river are the results of drainage above, are subterfuges for the purpose of securing National appropriations. The Nation has a duty toward the Mississippi River and toward all other streams which overflow so as to cause damage; but it would be far better to establish that duty by an accurate analysis of the Nation's interest as compared with other interests.

The author's remark in the discussion of the Kansas City problem, (Par. 137) that in this instance a great opportunity was missed for the complete solution of the problem, gives opportunity for the observation

Mr. Morgan. that the Nation doubtless is fortunate in not entering suddenly upon a large program of flood prevention. For the proper solution of our flood problems, the element of time is absolutely necessary. With the steady increase of technical data with the increasing background of experience, and with the broadening of our points of view and the giving up of preconceived opinions as to methods commonly held by the public, year by year we are becoming better able to do permanent and effective work. Rapid improvements in construction machinery are making work which was impossible a few years ago entirely feasible. Much of our older flood-prevention work, if it were to be undertaken today, would be modified materially. The increase in technical data and the improvements in machinery probably are more rapid today than ever before. With these considerations in mind, it seems that a gradual development of flood-prevention improvements in this country will lead to more permanent and satisfactory results, than an extremely rapid development which would go beyond the limits corresponding to the present data and equipment.

In the discussion of the policy followed by railroads in determining the flowage space under bridges or through culverts, the author has indicated the present practice accurately.

The use of such formulae as Talbot's or Meyers' is so unsatisfactory that we soon must come to a basis of definite analysis. The following rough outline is suggested for such a method:

1: Determine the drainage area in square miles.

2: Assume a rate of run-off per square mile, depending on rainfall, surface slope, shape of watershed, character of soil, etc.

3: Decide what factors determine allowable heading-up at the opening—this heading-up being limited by danger of overflowing the track nearby, of overflowing property above, or by the necessity of avoiding the creation of dangerous velocities which would cause scour or other damage.

4: Having determined the allowable heading-up, the velocity is assumed to be the theoretical velocity due to that head plus the velocity of approach and less the loss due to contraction and friction. In open-span bridges this loss seldom amounts to more than 10%.

5: Having determined the run-off from the drainage area, by multiplying the rate into the area, and the velocity through the opening, by finding the velocity due to allowable heading-up plus the velocity of approach, the necessary size of opening is calculated directly.

As these are the factors which enter into the situation, an analysis by their use is sure to give better results than the use of a formula which has no analytical meaning to the person who uses it and which can fit the case only by accident, since it omits entirely such controlling factors as velocity of approach and allowable head at the opening.

As the popular fallacy concerning the relation of forests to floods is wide-spread and can be dispelled only by constant repetition of the facts, the author does well to refer to the subject. In this country we are in the unfortunate condition that if one certain department of the Government issues a report by one of its scientists of an investigation of the subject, we need know only what department issues the report to know that the conclusion will be that the cutting of forests does increase floods; while if the report comes from a certain other department, we know equally well that the conclusion reached in the investigation will be the exact opposite. It is difficult to make real progress while this condition lasts. Mr. Morgan.

Mr. Morgan states that in two or three particulars his own impressions do not coincide with those of the author. He is familiar with the deep, loose, loam soils of the virgin forests of the Green Mountains, the Adirondacks, and the Laurentian Mountains of Canada, and did not suppose that these soils were more compacted than those of fields. The author's paper reached Mr. Morgan in the Green Mountains of Vermont and he took occasion then to check some of his impressions by experiments on loose forest soil in a hemlock woods, on apparently compacted pasture land, and upon meadow land. On a limited area of each soil he poured an equal amount of water, equalling two or three inches of precipitation. To his surprise the three kinds of soil took up the water in about the same length of time. Observations made in Arkansas a few years ago convinced him that variations in soil control to a very great extent the run-off of heavy rains, and that forests have little effect in comparison.

He has determined by personal examination that in the great hardwood forests of Minnesota the leaf mulch under the trees usually prevents the ground from freezing at all, while in the same vicinity exposed fields frequently freeze to a depth of 4 feet or more. It would be expected that in the spring the melting snow would enter more rapidly the wood soil than the frozen soil of fields or pastures, and that, in this respect at least, forests would tend to reduce the flood flow.

In northeastern Mississippi, the cutting of forests has resulted in the formation of hundreds of miles of gullies and newly formed watercourses, at the same time filling up the channels of the larger streams. He does not doubt that in this instance the cutting of forests has increased flood-flow and flood damage. His belief is that while the popular opinion concerning the relation of forests to floods is for the most part a fallacy, still it is not safe to come to conclusions in any particular case without knowing the facts; and that in some important instances forests may have an important part in increasing or reducing floods. Here, as elsewhere in engineering, generalizations are dangerous.

Mr. Morris Knowles,* M. Am. Soc. C. E. (by letter), expressed his admiration for the conciseness of General Chittenden's able digest of problems confronting hydraulic engineers in the control of floods, and desires to discuss the subject from a somewhat different point of view. Mr. Knowles.

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Mr. Knowles. Flood control is peculiarly a community problem. Like all great destructive agencies, floods afflict not only those whose property or whose lives they sacrifice, but also all those who are related to them by ties of blood, association and business. Indeed, it may be said that there scarcely can be a great destructive flood which does not visit its influence on all to some extent. Under existing laws and régime, it is largely for this very reason that actual steps for the control of floods are taken so tardily. "What is everybody's business is nobody's business", and too often the resolve for future resistance, made in the midst of the horrors of the flood, has led to naught because of lack of concerted effort and effective organization.

It is not that the technical problems of flood control are not now capable of solution. General Chittenden's paper illustrates the comprehensive grasp of the flood problem to which the engineering profession has attained, and no more convincing proof could be had than that hydraulic engineers today are prepared to attack without hesitation the greatest flood problems that America presents; though engineers are not, it is true, in agreement as to all details. Thus, while in complete harmony with General Chittenden upon most of the fundamental points, Mr. Knowles cannot agree entirely with the broad statement that forests have no influence on stream-flow. He is convinced that the effect on moderate floods and on the severity of drought, of forests located on steep slopes, is of some importance; and that the truth lies somewhere in the middle ground between those extremists who propose the control of the Mississippi by reforestation on the one hand, and those who, on the other hand, deny entirely such relationship between forests and flood control. Neither can he pass unchallenged in a technical discussion the statement that erosion due to deforestation has, as a rule, no effect on the filling of stream channels. He regards also as a dangerous doctrine, the view that "on most rivers, the tendency of human occupancy is to improve the carrying capacity of streams". No doubt it may be true that such occupancy does tend to improve the smoothness of the channel and to decrease its friction factor, but flood history presents too many disastrous proofs that such improvements too often are inadequate to compensate for the decrease in flow cross-section due to encroachments.

However, in the present status of the subject, agreement or disagreement on these technical aspects of flood control is not of prime importance. Engineering consideration of flood control in America faces a paradox today in that its most serious and vexing problem is not an engineering matter at all, but a legislative and financial one. The prime necessity of the moment is an adequate method for coordinating the efforts of communities desiring relief from floods, legislation which will give effective form to their civic spirit, and the provision of the necessary funds by an equitable system of taxation and assessment of benefits and damages.

It is impossible within brief limits to more than outline a few of

the essential features of such a plan. Above all, cooperation must be its guiding principle; and its foundation must be a workable form of organization and a just method of distributing the cost. There is no doubt that this is practicable. The Ohio Conservancy Law, while not perfect, is an admirable beginning and may serve well as the stepping-stone to America's emulation of the "Genossenschaften" of Germany. However, there are two other considerations of as great, or almost as great, importance as these fundamental essentials. Mr. Knowles.

First, such legislation must not ignore the fact that, broad as is the subject of flood control, it is still but one phase of the still larger and more important problems of water conservation and stream regulation. The greatest good to all the people, and efficiency, economy and prevention of conflict, all require that flood-control plans should be subject to the review of Conservancy Commissions; and that such commissions be endowed with ample resources and authority and charged with the harmonizing of local interests and the coordination of the needs of water-supply, water-power, flood control, navigation, drainage and irrigation. State and Federal Commissions should be required to consider and pass upon intra-state and inter-state projects, in order to make possible the consideration of each stream as a unit from its source to its mouth, for all its uses.

Second, such legislation should emphasize the need of continuing study and research in all branches of flood control, and of the most painstaking scientific investigation preliminary to the adoption of plans for construction. Above all, there should be no more legislation of the "pork-barrel" type; and, except in the case of a few projects of proven worth, legislative appropriations for specific projects, and not considering the stream as a whole, should be opposed firmly.

Also the research and investigation needed so badly can be carried on in no way better than by the organization of the Conservancy Districts and Conservancy Commissions that have been suggested. Such enabling legislation need not wait until after such investigations have been completed; and even if a few such districts are carried away by their enthusiasm for seeing the dirt fly before adequate comprehensive plans can be formulated, the harm thus done will be immensely less than if nothing is attempted or if legislation specifying technical details of projects is permitted.

Although the most pressing problem now is not strictly an engineering one, nevertheless engineers are usually well equipped as citizens to contribute to its satisfactory solution; and this Engineering Congress, representing all of the National Engineering Societies, could perform a signal service to the community by formulating the engineering principles of such model conservancy and flood-control legislation, and enlisting the Engineering Profession to aid in its passage.

Paper No. 31

FLOOD CONTROL IN CHINA.

By

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The history of attempted flood control in China dates from the sixty-first year of the reign of the Emperor Yao, 2297 B. C., and the technical knowledge of the engineers at that time would indicate that flood control was no new thing. From 2297 B. C. until today there is a more or less continuous record of the war between the floods and the people.

The methods employed have always been the confining of the waters and the protection of the land by dykes and the draining of the land by canals. There has been no attempt to lessen the evils of floods by holding back the waters with high dams and reservoirs. Small reservoirs are much used to impound water for local irrigation, and the outlets of most of the lakes have crude, movable dams for the same purpose. In most cases flood control, land protection, and irrigation have gone hand in hand, and by far the greater part of this work has been done in the great delta plains of the Yangtze and Yellow River Systems.

It may be taken as a fact that all of the rivers flowing through this delta plain have their waters more or less confined by dykes from where they enter the plain to the sea. This applies to the Yangtze River, from near Ichang, for one thousand miles; to the Han River for four hundred miles, until it enters the Yangtze at Hankow (these Han dykes are on both sides of the river, and in places are thirty feet high); to the Yellow River from Meng Hsien to the sea, about three hundred miles; and to all the other rivers entering this great delta

plain of the north or the delta plain around Canton in Southern China.

In addition to the dyking of the rivers, the delta from Hangchow on the south to Tientsin on the north—eight hundred miles—is a network of canals for a width of one hundred to one hundred and fifty miles west from the sea.

Within the area from Ningpo to the Yangtze, one hundred and eighty miles, and from the ocean west some one hundred sixty miles, there are over twenty-five thousand miles of canals, great and small; and none included are so small but that two small native boats may pass each other. (Fig. 1.)

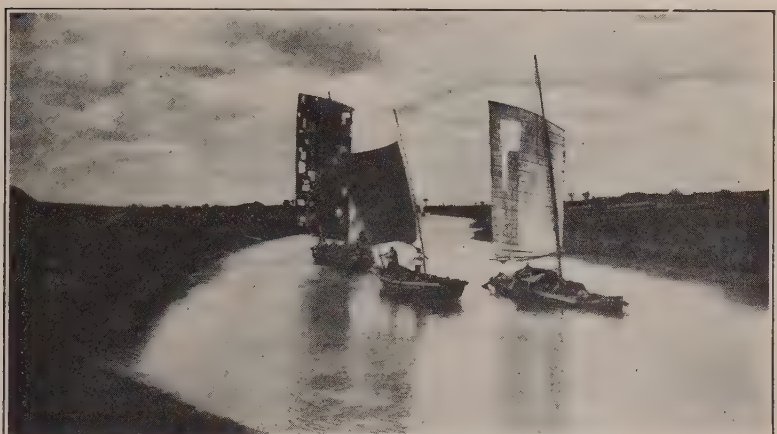

Fig. 1. Canal near Soochow.

From the Yangtze north to the old bed of the Yellow River and east of the Grand Canal, one hundred and twenty miles by one hundred and thirty miles, there is this same network of canals. North of the old bed of the Yellow River, it extends to the borders of Shantung, and north of Shantung, to Peking, with a diminishing number of canals. In this great delta plain of the Yangtze and Yellow Rivers there are not less than sixty thousand miles of canals for transportation which also serve for irrigation, drainage, and flood control.

As protection from the ocean tidal waves, there are, south of the Yangtze, some three hundred miles of sea wall; and from

the Yangtze north, for over one hundred miles, the great Maritime Dyke, built in 1027 A. D. (Plate II.)†

The actual number of miles of dykes, canals, and sea walls in the Canton Delta cannot be stated, but they run into thousands of miles.

From these facts some idea may be formed of the tremendous amount of work which has been done for flood control and land protection during the last forty-two centuries. During this period, at least, we know that the Great Delta has been under cultivation and that the people have made a continuous effort to confine the rivers between artificial dykes. Of all these rivers, the Yellow River has been preeminently the greatest cause of sorrow and devastation by its floods and ever-changing channel. The Yellow River may be taken as an extreme type of all that is evil in rivers. All the conditions under which it exists and moves to the sea are economically wrong; and the story of the Yellow River will fully illustrate forty-two centuries of warfare between man and nature, each striving to accomplish its allotted work—the river to build a continent, the man to feed himself and others. (Plates I and III.)

The Yellow River rises in the plain of Odontala, in Thibet (called by the Chinese the Starry Sea, from the great number of springs through that whole region), and is some three thousand five hundred miles long by its present channel.

It is a composite river, formed of sections of streams which were formerly quite separate, but are now joined in consequence of the activity of well known processes by which rivers develop.

The history of the river goes back to a time before the uplift of the present mountain masses. It may be the story of the struggle between two rivers, as it appears to be, and that struggle may be suggested as follows:

Once upon a time there existed in eastern China two rivers, the old Yellow River and the Wei River. The old Yellow River consisted of the upper course of the river rising in Thibet and flowing northeasterly; beyond the point where it now turns abruptly south it then continued easterly, probably to Kalgan,

† Plates II and III are taken from "Le Canal Imperiàl", par LeP. Gaudar, S. J., Shanghai, China.

Peking and the sea. From this point where the river now turns south to Kalgan was not the bed of ancient lakes. This is clearly shown by the character of the deposits, and traces of this old Yellow River bed are still discernible.

The Wei River rose in the valley of Sian fu, and at one time, possibly, flowed to the southeast by the Hua Shan and emptied into the Yangtze River. Later, this channel was closed and the Wei River flowed east past the Tung Kwan and discharged, probably, along the course of the lower Yellow River of today into the delta plain of eastern China.

The Wei River probably had a tributary which entered it from the north at Tung Kuan along the line of the north and south course of the great river of today.

These systems existing, the gradual elevation of the mountain ranges produced certain marked changes. The old Yellow River was checked in its flow to the east by the Khing-an range, which was raised across its path. The north and south tributary to the Wei River was quickened in its southward flow by a downward tilting of the plateau, in that direction, toward the great Hua Shan range. Being thus quickened, it grew at its head as it deepened its channel in the rising plateau. Growing northward, it reached the discouraged Yellow River, captured it, and turned its waters southward along its present course.*

The point of discharge into the sea has changed many times, covering most of the delta coast line from Tientsin to Hangchow, points eight hundred miles apart. The building of the delta continued. There are no evidences of any "diastrophic uplift of the sea bottom above the water surface, thus forming the base of the delta plain." There was, undoubtedly, a certain width of delta plain extending along the foothills from Tientsin to the Yangtze when the Yellow River came south. It began to build its own delta, and unconfined, it swung back and forth over the plain, crushing man and his works at every move. If it had been left to itself it would have, in time, established its delta gradient, built up the country level and made for itself a definite channel; but man interfered.

* The writer is indebted to Mr. Bailey Willis of the United States Geological Survey for these notes on the growth of the Yellow River.

Much of this delta plain was under cultivation and probably much was undrained swamps. The Emperor Yao, in 2297 B. C., commanded Kwan to confine the rivers to definite channels and drain the land. For nine years he worked at his task, with no permanent results, and at last retired, leaving his son, the Great Yu, to complete the work. Yu, after seven years, succeeded. The waters of the rivers were controlled and the swamps were drained. Yu was China's greatest engineer, an authority and writer upon flood control, reclamation, irrigation and agriculture; and, eventually was an Emperor of China.

Yu, for the good of the people, confined the Yellow River between dykes. These dykes at first were several miles apart. The low water channel meandered from side to side. The building of the required gradient continued within the dykes, and the surface of this confined area was raised above the country level. In years of low water and no floods, the elevated, well drained and rich flood plains were cultivated and gave rich returns. In ordinary floods, all this was lost. The people were eventually allowed to build inner lines of dykes. The flood level was thus raised, both lines of dykes often broken, and the river swept over the country to the north or to the south. Sometimes the dykes were repaired and the river forced back into its old channel. At other times it swept on to the sea at some new point and, eventually, new dykes were built, and with care all went well until it moved again. (Plate IV.)

The maps show its various courses from the time of Yu to the present day.* Many of these ancient channels may be traced today upon the Great Plain north of the Promontory of Shantung by the well defined remains of dykes and flood plains, and by the names of some of the small towns indicating that once they were on the bank of the Yellow River.

Notice that the first mouth of the Yellow River from the time of Yu to 630 B. C.—1667 years—was from Tientsin to the sea, the same point of entry it had followed when coming from the northwest.

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* These maps are reproductions from "Geological Researches in China, Mongolia and Japan, 1862 to 1865", by Raphael Pumpelly, and were made from Chinese maps.

In 1852 the Yellow River made its last great change, moving its mouth north some two hundred and fifty miles and deserting the channel through which it had flowed for five hundred and twenty eight years. At no time in the history of the Yellow River has it cut itself a definite channel below the level of the delta plain. The fact which has prevented its building a natural delta gradient has been the tilting of the great plain. (Plate I.)

Along the foothills bordering the Great Plain there is a warp extending from Peking to the south side of the Yellow River, thence west, parallel with the river, to beyond the Tung Kuan. The land to the east of this warp subsided and this movement has never entirely ceased, while the sea coast north of the Shantung mountains and to some extent the mountainous promontory itself is rising. Consequently, the Yellow River and all the other rivers north of Shantung have always had to work against this constant tilting of their beds in a direction opposite to their flow.

The actual slope of the Yellow River across the delta plain is about one foot per mile, but even this slope is not sufficient to carry the immense amount of silt to the sea. Much of the course of the Yellow River is through loess deposit, an aeolian deposit which is most curious. Its particles are so fine as to make an almost impalpable powder when crushed in the hand. In the original deposit, the cleavage is vertical and in two directions at right angles to each other. When undermined by water, it splits off in immense slabs or needles, and in water it falls apart and appears to melt like sugar. Either in its natural position or laid in horizontal layers by water, it is most pervious to water. The deposits are in some places two thousand feet in thickness. (Fig. 2.)

There is a dual flow in that portion of the Yellow River across the plain. The top flow is the water with all the silt it can hold in suspension, moving at some twelve or eighteen feet per second; below this, rolling along the bottom of the channel, there is a mass of thick, liquid mud of varying depth, moving at a very much less speed.

In ordinary rivers the discharge grows continually greater from the source to the mouth. In the Yellow River this is not the case. From the point where it enters the Great Plain to

Fig. 2. Yellow River Crossing of Peking-Hankow Ry. Cave Dwellings in Loess.*

the sea, four hundred miles, it has but two tributaries, the Chin River from the southern border of Shansi, a short river with an unimportant amount of discharge, and the small Ching River

* The author wishes to acknowledge his indebtedness to Prof. Daniel W. Mead for photographs, Figs. 2, 5, 12, 13, 14 and 15.

in Shantung. The banks, dykes, and bed of the Yellow River are of permeable material. The water level is above the surface of the adjacent country, and great areas of swamps are found on each side of the river beyond the flood plains. The volume of discharge decreases constantly in its course across the plain. There is no record of the actual discharge at any point, but the diminution is obvious. The river is not in any sense navigable at its mouth for even small boats, and in its entire length it is not navigable in any but short reaches by small native boats.

The Yellow River being a river by itself,—in the youthfulness of its present channel, the material through which it flows, the centuries covered by its history, and the peculiar condition under which it does its appointed work of continent building—is the writer's excuse for this long preamble before describing the actual methods used for flood control.

The universal method of flood control in China is the confining of the rivers by artificial dykes. There has been no attempt at holding back floods by large dams.

In what may be called the semi-arid sections, numberless small reservoirs are built by individual landowners and water impounded for use in times of drought. Much wonderful work has been done in the conservancy of water for irrigation purposes, especially in the rice-growing portions of China. But dykes are the universal method of protection from floods. The materials used and the methods employed are much the same in all China, and a description of the dykes of the Yellow River will serve for all, the variations being merely in size, depending upon the varying conditions obtaining.

THE YELLOW RIVER DYKES AND DEFENSE WORK.

The earlier dykes built upon each new channel of the Yellow River were built two or three miles apart, with a certain amount of regularity, with long curves and no sharp angles. Those built after the change of channel in 1852 illustrate this well. (Plate V.)

The river had a wide flood channel and meandered from side to side in its low-water channel. No attempt was appar-

Fig. 3. Finished Dyke.

ently ever made to train this low-water channel. As the flood channel silted up, this rich land became valuable and the natives were allowed to dyke it off in any irregular manner they pleased, with no regard to the training of the river.

Fig. 4. Building Dykes, showing Borrow Pits.

All of these dykes are built of earth with slopes of about three to one. (Fig. 3.) The earth is taken from borrow pits parallel to the dykes, transported in wheelbarrows or baskets and put on in layers from one to two feet in thickness. (Fig. 4.) Each layer is thoroughly tamped. The tamping is done with a disk of stone or iron some fifteen inches in diameter and two and one half to three inches thick. To the edge of the disk are fastened eight or ten ropes at equal intervals. With a man to each rope, they give a quick pull in unison, the disk is thrown up, and falling, tamps the earth. (Fig. 4.)

Fig. 5. Finished Dyke, with Kaoliang Buttresses and Stacks of Kaoliang for Repairs.

To ascertain the sufficiency of the tamping, a highly polished, pointed iron rod, about one-half inch in diameter, is run a foot or two into the tamped earth, withdrawn, and the hole filled to the top with water. If the water does not sink away, the tamping is sufficient, but if it begins to sink at once, why, then more tamping.

These are the dykes as built, and nothing more is done until, through the impingement of the water, a washing away begins. Defense and protective methods are then used. When on straight pieces of dykes, the protection works are com-

paratively effective. (Fig. 5.) It is where the current impinges at an angle that the serious difficulties occur.

DEFENSE AND PROTECTION WORK.

In this paper the term defense and protective work means any works built along the face of the dykes to protect it from the action of the current, also, deflecting groins projecting from the dykes into the river bed.

The following description is taken from "Notes on the Hwang ho or Yellow River" by W. Ferd Tyler, Coast Inspector, Chinese Maritime Customs, Shanghai, China.

The material universally used for this defense work is Kaoliang stalks* or certain rushes growing wild in all the marshes. At present, on the Yellow River, some of this protective work is constructed of stone rip-rap or dry-stone masonry.

The following sketches will give some idea of the form of the Chinese work. (Fig. 6.) In no case is there a smooth protective facing of Kaoliang. It is always built in detached pieces of the forms shown in the sketches. As the care of the dykes decreases, the bastions become separated as shown in *Fig. 5* of Fig. 6. The building of the fish-scale bastions, rather than a smooth curtain, was a necessity, due to the character of the material used. It is probable that the ancient Chinese engineers, who had great skill and knowledge in this matter, used a system of deflecting groins in conjunction with a continuous curtain of fish-scale protection, and that the present practice is a degenerate form of this original. Much of the irregularity, however, is due to the irregularity of the dykes, and also to the subsidence and slipping of the bastions, which are then repaired and built up in this new position. While the Chinese violate many principles in the design of these works, still their methods of making use of this feeble material for the construction of their huge works shows a skill that excites one's admiration.

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* The Kaoliang (sorghum vulgare) used is the purple grain variety which grows some eight or twelve feet high, and which is grown through all central, western and northern China and Mongolia. The grain is used for food and for the making of a Chinese whiskey.

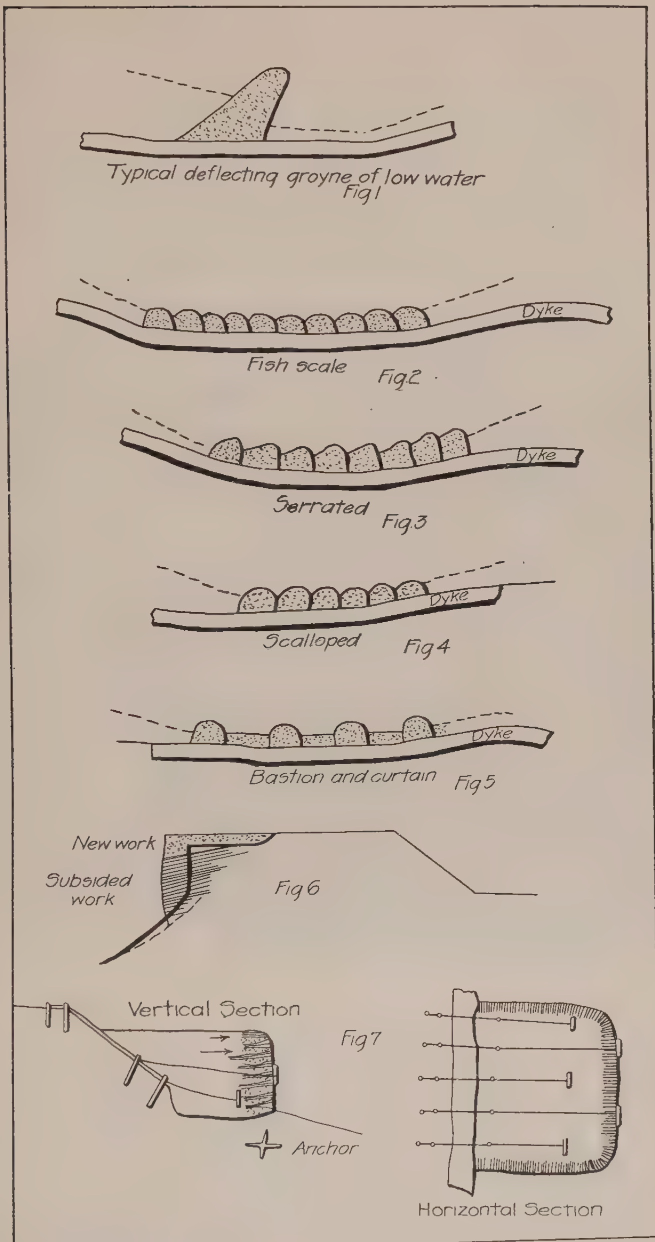

Fig. 6. Types of Chinese Protection Work.

The Kaoliang stalk, with the exception of a thin, hard covering, consists entirely of pith. It has a bunch of hard, strong matted roots and is eight feet or more long. (Fig. 6, *Fig. 7*). The Kaoliang defense works are built up of successive layers of Kaoliang and soil. They are anchored to the dyke by ropes. The face and sides of the works are composed of the matted roots. The details may vary some, but general methods are the same in all China. After new works have been

Fig. 7. Usual Method of Kaoliang Construction.

built with the successive layers of Kaoliang and soil and exposed to the flood waters, the soil is washed into the interstices between the stalks and the stalks themselves become crushed. (Fig. 6, *Fig. 6*). The whole work settles and often slips forward some; and often the scour beneath the groins is sufficient to overthrow the whole work. If it is not destroyed, the repairs, if any, are made directly upon the deformed work,

and as this is done to some extent each year or two, the original alignment is soon lost. (Fig. 7.)*

On the rivers north of the Yangtze the anchor ropes used are usually made of straw, which in a short time decay and become useless. In some few cases, the ropes are of hemp or platted bamboo. A facing of dry masonry is useless, as no proper foundation nor protection for the toe is made. A much better method is the use of stone as rip-rap in sufficient quantities to reach well up on the face of the groins and well out on

Fig. 8. Stone Deflecting Groine.

the river bed, making an apron. In some few cases, the Kaoliang bastions are protected by a facing of willow-basket work, the use of which might well be extended if the proper kind of willow (osier) were grown for the purpose. Mattresses, as used on the Mississippi and other American rivers, are not used at all by the Chinese, but have been used to a small extent in

* Figs. 7, 8, 9 and 11 are from ''Notes on the Hwang ho or Yellow River'', by W. Ferd Taylor, Coast Inspector, Chinese Maritime Customs, Shanghai, China.

the foreign designed conservancy work of the Hai ho, between Tientsin and Taku.

For the care of the dykes on the Yellow River there is a special department, very well organized in theory but most slackly administered. The river is divided into sections and is in charge of men whose fathers, grandfathers, great-grandfathers, etc., were born and brought up to this work. These men understand their work quite well, but the men higher up

Fig. 9. Kaoliang Protected by Basket Work.

know nothing of flood control, are changed often, and take no interest in the work. All the money appropriated is in their charge and but a small percent only passes through their hands. With proper, ordinary, continuous care there is no danger of a break in the dykes, but some care is necessary.

Breaks do come in the dykes from time to time. (Plate IV.) In some cases the whole river breaks through and seeks a new channel, as in 1852. But in very many cases the break

is repaired and the river forced back into its old channel. The following description of the mending of a break, in 1902, will illustrate what the Chinese can do in an emergency with such light, weak material as Kaoliang. (See Plate VI.)

The break occurred at Liu-wang-chuang, September, 1902, and was finally closed March, 1903. Some 1500 yards of the dyke was carried away and the greater part of the water flowed through this breach. The closing was effected in the following manner. (Fig. 10.) A dam was run out from either side of the breach by the successive building of Kaoliang buttresses. When these approached within fifty-five feet of each other, a

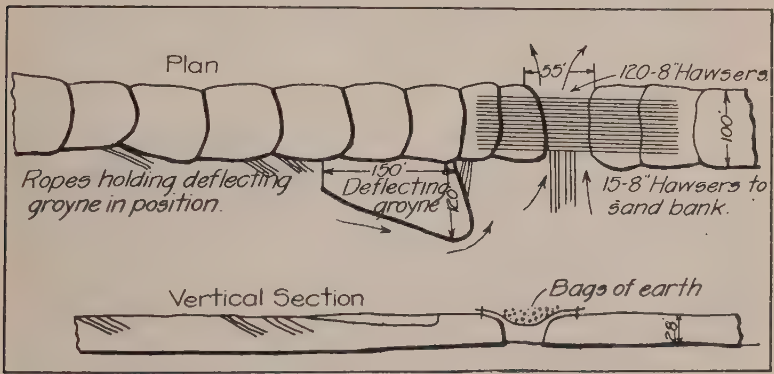

Fig. 10. Closing a Breach in the Yellow River Dyke.

huge deflecting groin of Kaoliang was built on the up-river side of the opening to minimize the rush of water through the aperture. The width of the channel abreast of this breach was about six hundred feet, but this was reduced to less than three hundred feet by the formation of a sand bar growing out from the opposite shore. When the opening had been restricted to fifty-five feet, ropes were stretched across it and belayed to anchor piles. Over one hundred eight-inch ropes were used, spaced close together. On these were then placed, in alternate layers, Kaoliang and sacks of clay. When these materials were up to the level of the dam, the ropes were manned and at a given signal were each slacked one foot on each side. The mattress so formed was again added to with Kaoliang and clay, and again lowered and so on.

On the first attempt to close the breach, on the 2nd of January, the mattress, when it felt the full strength of the current, canted and capsized. It tore away a portion of one dam and many of the men on it were drowned. The process was again repeated, but this time five fifteen-inch hawsers were made fast to the mattress and led across the river channel and made fast to anchor piles in the sand-bank. Another failure occurred on the 11th of March, also with great loss of life; but on the 16th of March it was finally closed.

Fig. 11. Part of the Dam at Liu-Wang-Chuang.

The deflecting groin was a remarkable structure, projecting one hundred and twenty feet into the full strength of the current. It was tied up to the Kaoliang dam by an immense number of eight-inch hawsers. (Fig. 11.)

The above description will apply in principle to flood control of all the rivers in the delta plains of China—the confining of the waters between artificial dykes. Practically no effort has been made to lower the flood level and improve the run-off of the rivers, with the exception of the great amount of pre-

liminary surveys and studies which have been made during the last four years by the American Red Cross, in the Huai River basin, which we will now consider.

HUAI RIVER CONSERVANCY.

More work has probably been done and more money expended upon flood control during the last two thousand years in and for the section of country east of the Grand Canal and from the Yangtze River north to the old bed of the Yellow River, than in all the remainder of China. (See Plate VII.) This is a low, flat section but a few feet above sea level. The soil is very rich and the climatic conditions suited to the culture of rice and wheat. Bordering on the Grand Canal and being covered with a network of secondary canals, it has been in touch with China's markets for three thousand years. Not only was it the granary of China, but the whole sea coast was and is one vast salt manufactory.

Before the coming south of the Yellow River, in 1324 A. D., the Huai River went to the sea in what is now known as the old bed of the Yellow River, flowing through the Hungtze Lake, which was then but one quarter its present size and of very considerable depth. The records of this section are quite complete from 450 B. C. to the present day; they are records of floods, loss of life and subsequent famine, together with a continuous fight by man against these forces of nature. (Plates I and III.)

The floods not only destroyed the crops, but, sweeping to the sea, ruined the salt works which lined the coast; and when there were no floods, immense tidal waves rolled in from the sea and destroyed the rice paddies. During the Tang Dynasty (1027) there was built the Great Maritime Dyke, extending from the Yangtze River to the Huai, parallel to the coast between the rice paddies and the salt pans. This dyke had eighteen gates for the passage of the flood waters to the sea in definite channels. It was fifteen feet high and was surmounted by forty-three towers, twenty feet high, from which signals were given, by fire at night and smoke by day, of the coming of either flood or tidal wave. The gates were opened

Fig. 12. The Ming Dyke.

for the floods to pass and closed against the tidal waves. Parallel to the Maritime Dyke is a canal for the transport of salt. The Grand Canal passes north and south through this whole section at nearly right angles to the natural line of flow. The waters are held in place by artificial dykes, and for greater

Fig. 13. The Ming Dyke.

portions of this distance the water level is above the surface of the adjacent country. The country on the east is much lower than that on the west side, owing to the gradual silting up of the land to the west. The Yellow River came south in 1324, and, at the east end of the Hungtze, appropriated the channel of the Huai. When in flood, the waters of the Yellow River backed up the Huai, raised the Hungtze Lake and flooded the entire country, north, south and west, often breaking through into the shallow lakes west of the canal, carrying away the canal and dykes and inundating the low country to the east. Time and again this happened. Flood openings were made at the southeast side of Hungtze Lake, and every effort was made to so enlarge the channels through the lakes to the Yangtze that the floods might pass without damage. This desired result was never attained. To control the outflow of the flood and protect the Grand Canal, the great Ming Dyke was built, sometime in 1400 A. D., by the first Ming Emperors. This dyke was thirty-five miles long, built of earth, some twenty-five feet high and the top served as a broad highway. Several times it was broken and repaired. In the Manchu Dynasty, under Kang hi, much flood control work was done in this section and the entire Ming Dyke was faced with cut stone. (Figs. 12 and 13.) It stands there today as a great example of what Chinese Emperors did for their country when Emperors ruled.

The building of dykes and canals was not the limit of flood control measures. The people implored their gods and gave them money, food, and rich raiment to the banging of gongs and the rattle of firecrackers; but still the rain fell. They stripped the gods and set them in the open courtyards they that might experience the discomfort. Not a god made a move, the rains continued and things were bad at the beginning of the Ming Dynasty, 1368. The new Emperor and his Prime Minister found an infallible remedy against rains and floods. There were cast nine oxen, two tigers, and one cock with hearts of gold and intestines of silver and they were placed at the critical points. Hungtze Lake had at Kaoliang Hsien an ox. As years passed, the oxen lost their flood eliminating powers, and during the reign of the Great Manchu Emperor, Kang hi, floods and destruction came. A censor of

the Empire, in a memorial, made known the cause. The Ming ox was tired and covered with rust. Greedy persons had stolen the heart of gold and intestines of silver. Kang hi ordered new oxen made, and the Great Emperor himself visited Hungtze Lake and the town of Kaoliang Hsien when the new ox was put in place in 1703. The ox is still there, quiet and couchant, also a stone tablet telling this story and also the floods.

These great floods and the subsequent famines were brought to the attention of the Western nations by the foreign missionaries some twenty-five years ago, and money and provisions for relief have been donated. (Figs. 23 and 24.)

Great floods and severe famines characterized the years of 1909 and 1910. Hundreds of thousands of people perished. The American National Red Cross sent out some sixty thousand dollars in money and several ship loads of provisions. It then, through the American Department of State, advised the Chinese Government that, if it approved, the Red Cross would send an engineer to make a study of the flood and famine region as to the possibility of lowering the flood level and thus eliminating the floods and the subsequent famines. The offer was accepted, and the writer, who had lived and worked in China for sixteen years, was appointed to make these studies. The practical elimination of floods was found possible at a cost which made it justifiable from a business viewpoint. In February, 1914, the writer returned to America with a preliminary agreement signed by the Chinese Government and by the American Minister on the part of the Red Cross. In June, 1914, a Board of Engineers, Colonel W. L. Sibert, A. P. Davis, and Daniel W. Mead, with the writer as General Adviser, returned to China for a final examination of the region, with the assistance of four years' accurate surveys made by Chinese surveyors, and to report upon the works necessary, with the probable cost. The report was handed to the Red Cross the last of October, 1914.

The conditions at present are as follows: After the Yellow River came north and joined the Huai, in 1324, the floods of the Yellow River backing up the Huai into the lake were always a menace to the Grand Canal from the west. Nothing

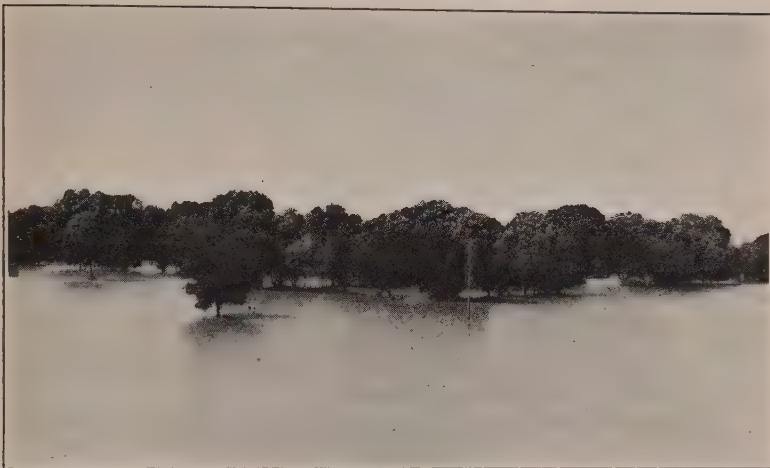

Fig. 14. Floods North of Peng pu, Sept. 1914.

could prevent destruction as long as the Yellow River was allowed entrance to the Hungtze Lake. Consequently, the great dyke of the Yellow River was carried across the Huai River, cutting off its outlet to the sea. Part of its flood waters passed into the Yangtze through the lakes west of the Grand Canal.

Fig. 15. Huai River in Flood near Peng pu, Sept. 1914.

Hungtze Lake silted up until the bottom of its outlet into the canal has the same elevation as the bottom of the Huai River at Huai Yuan Fu. The lake trebled in size, and the floods, having no sufficient outlet, backed up and flooded the country.

What is needed is an outlet with sufficient capacity to lower the flood height to a certain fixed maximum elevation. In deciding what this elevation should be and what control works are needed, the following problems must be considered.

The elevation of the water in the Grand Canal must be held between a fixed maximum and minimum.

The depth of water in the Huai River, from the outlet at Thsiang Kia pa to Huai Yuan, must be maintained at a navigable minimum during the dry season.

The works must be so designed as to allow of the drainage of the greater part of the Hungtze Lake, and arrangements must be made for the complete draining and irrigating of this reclaimed area.

The low country to the east of the Grand Canal is dependent upon the Grand Canal for irrigation in dry seasons and the necessary water is supplied by the Huai River. The drainage and reclamation of the shallow lakes and swamp lands north of the Hungtze Lake and west of the Grand Canal.

The reclamation of as much land as possible from the swamps and lakes west of the Grand Canal, from Thsing Kiang pu to the Yangtze River.

The project recommended by the Board of Red Cross Engineers is shown on Plate VII.

The total discharge of the Huai River will leave the Hungtze Lake at Tsiang Kia pa, and what is not needed for irrigation will flow into the Yangtze.

The water needed for the canal and irrigation will be regulated by control works and locks.

The estimated cost of the works is thirty million dollars, and if the interest on the bonds is paid from the proceeds of the loan, about fifteen million dollars additional will be required—with the interest at 5 per cent, the bonds selling at 90 and an interest of 3 per cent secured upon unexpended balances.

The estimated returns from the reclaimed lands and lands benefited are placed at forty-eight million three hundred and fifty thousand dollars, and there should be received annually after the six-year period of construction:

From the revenues of the Grand Canal and other canals in this area a net return of	$ 225,000
From taxes on land	2,136,000
	$2,361,000

These estimates are from the Report of the Board of Red Cross Engineers.

DISCUSSION

Gen. William L. Sibert,* M. Am. Soc. C. E. (by letter), stated that the flood problems in that portion of China with which he has some acquaintance (that part of the great plain lying between the Yangtze and Yellow Rivers) are unusual ones. Gen. Sibert.

The average annual rainfall is less than in the eastern part of the United States; but in some years such rainfall may be more than double the average, coming in storms of great intensity; in this area a record is known of 25 inches of rain in two days. The general slope of the country toward the sea is about five or six inches per mile. Practically all of the rain comes during the months of July, August and September, which means that an overflow always destroys actual crops.

The Chinaman expects his land to produce two crops a year, and it is the second crop that is subject to destruction by floods. The first crop generally is wheat, and is harvested in June and hence seldom is caught by the floods. The second crop ordinarily is beans and peas.

The typhoons which sweep over the Philippines and across the Yellow Sea pass over the land in this part of China and are accompanied by the intense rainfalls mentioned above. While 25 inches of rainfall in 48 hours are usual, 4 to 8 inches in from one to three days are a frequent occurrence. In a flat country, such storms not only cause the streams to overflow their banks, but also submerge the lands directly by the rainfall. In large areas crops are often destroyed because of the inability of the rain-water to find its way quickly into the streams. The flood problems therefore are complicated seriously with drainage problems, and often with irrigation problems. The thousands of miles of great and small canals referred to in Mr. Jameson's paper, were built largely to give additional stream-discharge area for the disposition of local rainfalls. In some places, also, the material

* Brig. Gen., Corps of Engineers, U. S. Army, Fort Miley, San Francisco, Calif.

Gen. Sibert. excavated was needed in building up the land so that it could be cultivated. Usually navigation was a secondary consideration.

The report on the Huai River Conservancy Project made by the Board of Engineers sent to China by the American National Red Cross, was printed by that organization in pamphlet form and probably a copy may be obtained on application. This conservancy project is not an ordinary problem of flood amelioration, but one complicated by the necessity of providing an outlet for the Huai River; its natural outlet to the sea having been destroyed by man in building the Grand Canal, and by the Yellow River during its recent 500-year visit to that locality.

In general, China has attempted to prevent the overflow of streams by levees and has been doing such work systematically for more than 4000 years. In protecting the levees, the engineers apparently have not adopted an effective system of bank protection, their efforts to prevent bank erosion being confined to work near the water's surface instead of at the foot of the bank and on the bottom of the river in front of the bank. The patience, energy and ingenuity of the Chinaman in draining his land and in building levees to protect it are impressive; and an inspection of such work always brings a feeling of regret that the vast amount of energy expended was not accompanied by more knowledge of the theory of "Stream Flow".

The United States remitted a large part of the Boxer Indemnity allotted to her on condition that the same be utilized in paying the expenses of Chinese students in American Universities; and this may be a factor in providing the theory that China needs in her struggle to free her lands of floods.

Paper No. 32

WORKS FOR THE IMPROVEMENT OF NAVIGABLE ESTUARIES.

Notes by

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DIFFICULTIES IN THE NAVIGATION OF ESTUARIES.

There exist many rivers and lagoons which in their internal branches present conditions naturally sufficient to permit the passage of vessels, even of considerable draft, but which in the estuary—or where they open into the sea—are obstructed more or less by banks of sediment, changing frequently their position and form, and which constitute a grave obstacle to navigation. These conditions are especially met in the short reach which forms the actual mouth or outlet into the sea. Thus, estuaries which open into seas with moderate tidal movement, are commonly obstructed by a submarine bank covered with only a slight depth of water, which takes the name of "bar" and which forms a most serious obstacle to the free passage of ships.

The problem of holding an estuary free of these banks and especially of the bar, and thus maintaining a channel suited to the free passage of ships—thus permitting them freely to ascend the river—has been the object of long experimentation and of diligent research on the part of all students of maritime works, and has formed the subject of keen discussion in all the Congresses of Navigation. Notwithstanding the fact that since many years and for many estuaries this problem has been treated by various means and in a more or less satisfactory manner, the true solution is still the subject of doubt and of controversy among engineers of river and harbor works.

DREDGING VERSUS JETTIES.

By some engineers the best and most economical solution is held to be by means of an energetic dredging of the banks and shoals of the estuary and of the bar, continued actively in proportion to the tendency to re-establish themselves. This method has been followed for the estuaries of the Mersey, the Clyde and of the Scheldt, which give access to the ports of Liverpool, of Glasgow and of Antwerp, respectively. A similar method is followed for the estuary of the Plata, through which ships pass to the ports of Buenos Aires, Rosario and La Plata, and likewise with the best of results for the bar at the mouth of the Hudson, opening the Ambrose channel with a good 12 meters (39.36 feet) of water at low tide, which allows colossal ships, such as the "Olympic" and "Aquitania", to pass through and reach the port of New York.

With this method of treatment, however, there is a continuous struggle between the sea, on the one hand, which tends to re-establish the bar and the shoals of the estuary with the waste material which the river is carrying down, and the dredgers, on the other hand, which must incessantly labor to carry away this material in order to maintain a navigable channel open for traffic; and the greater the violence of the waves, the less the height of the tidal movement in the sea in which the estuary opens, and the greater the draft of the ships, so much the greater are the difficulties and the expenses, which increase almost with the square of the depth to be maintained. But thanks to the active commerce which these dredging operations secure, the port charges may be made sufficiently high to fully pay the cost of the incessant labor of Sisyphus, and to which are adapted dredgers often of extraordinary power, and some even with a capacity of 10,000 tons of material per hour, as for example the suction dredgers in use for the ports of Liverpool, Buenos Aires and New York.

In other estuaries, and especially for those of lesser importance, this excessive annual expense would not be possible, and in order to avoid such continued expense, engineers have made use of permanent works, intended to guide the water of the river beyond the bar and out into the deeper water of the sea. Such

means have been used for many Italian ports—Viareggio, Fiumicino, Sinigallia, Fano, Pesaro and Rimini—and for very many ports in other countries. In general, however, the results were so discouraging—at least for the ports with moderate tidal movement, such as those of the Mediterranean, the Baltic and elsewhere—that they were used by the partisans of the dredging method in order to sustain their arguments and to combat the claim of effectiveness for the ''jetty'' or ''training wall'' system as these protective works are called.

RESULTS OF JETTIES AND TRAINING WALLS AT VENICE AND AT THE DELTA OF THE MISSISSIPPI.

On their part, the partisans of the jetty system, in order to defend their point of view, cite cases resulting in brilliant success. Among these the classical examples are the port of Malamocco in the estuary of Venice and that of the South Pass in the estuary of the Mississippi, where the protective works, in the form of jetties and training walls, were so effective that the natural current, without the need of special or active dredging, opened and then maintained naturally a channel permitting ships with a draft of about 7.5 meters (25 feet) to reach, respectively, the ports of Venice and of New Orleans.

It is from these best and truly exceptional results that the partisans of the jetty system draw the argument to sustain their thesis and to demonstrate that it is much more economical to adopt this system, irrespective of the magnitude of the port traffic—even though the first cost is very high—rather than to depend on dredging alone, for which the annual costs of maintenance are nearly in proportion to the port traffic. But to this the advocates of the dredging system urge that the case of the port of Malamocco is exceptional, because it is not a matter of turbid waters but of those from the lagoons of Venice, which do not make deposits and which, with their alternate passage every six hours (by reason of the tide) through the channel left between the two jetties, carry away that part of the material which the waves of the sea, in times of storm, dig from the adjacent shores, transport in suspension and, having come into the zone of quiet water formed by the jetties, tend to deposit

there and thus to reform the original shoals wherever the tidal currents, and especially the powerful ebb current, is unable to drive them further and cause them to be deposited in deeper water.

And in case of the South Pass, at the mouth of the Mississippi, the current of the great river with its enormous volume of water of thousands of cubic yards per second, even in low stage—guided by the jetties across the shoals of the estuary—is sufficient to maintain a depth of about 9 meters (30 feet). To this the partisans of the dredging system observe that entirely similar works carried out at the Southwest Pass of the same Mississippi have failed to give satisfactory results.

AMERICAN EXPERIENCE.

All these varied problems, which, as above noted, have formed the subject of active discussion in the various international congresses of navigation, were discussed in a paper presented by Dr. E. L. Corthell—the dean of American maritime engineers—at a meeting of the American Association for the Advancement of Science held at Philadelphia in the past year.

He—who together with Captain Eads executed the work of the jetties at the South Pass of the Mississippi and, later, those of the River Panuco, to give access to the port of Tampico in Mexico—pointed out that in the case of the South Pass the jetties had the sole purpose of directing the current of the great river across the shoals and to the bar of the estuary and with such velocity that it should prevent deposit at a depth less than 26 feet (7.8 m), the minimum which it was desired to obtain; while in the case of the Southwest Pass it was pretended that the river not only should not deposit new material between the jetties, but that it should excavate upwards of two thirds of the enormous quantity of about 20 million cubic yards of alluvium which it was necessary to remove in order to form a navigable channel. Furthermore, the jetties at the Southwest Pass, instead of being extended to a depth of 30 feet (9.15 m), which it was desired to realize in the channel itself, were stopped at the depth of 20 feet (6.10 m). The consequence of this lack of length was that it was never possible to maintain in the said channel a depth of water superior to about 20 feet (6 m), and it was

found necessary to continually carry on dredging operations in order that it should not fill up again. Besides, Dr. Corthell observes that the jetties themselves, instead of rising above the level of the sea as much as might be needed in order not to be overtopped by the waves, were carried only 1.2 meters (3.94 feet) above this level. As a result, during high storm-tides the waves charged with detritus brought from the adjacent shores pass easily over the jetties and deposit such detritus between them, and thus, little by little, the navigable channel tends to load itself up with sand and detritus, with a consequent loss in the depth of water available for the passage of ships.

The result was that the natural current of the Mississippi at the mouth of the Southwest Pass was never able, by itself, to excavate the shoals which obstructed the channel, and hence there was necessary a true and definite work of dredging in order to remove some 20 million cubic yards of material, at an estimated price of 3 cents per cubic yard, which, in reality, rose to 16 cents per cubic yard. And notwithstanding this initial work and the succeeding work of maintenance with dredgers, it was never possible to obtain the depth of 27 feet (8.2 m) desired, but only a depth, as noted above, of 20 feet (6.1 m).

On the other hand, in the neighboring mouth of South Pass, the work of removing the shoals of the estuary was done almost entirely by the current of the river, aided only—to the extent of 1% of the total excavation—by the work of dredgers, which were used especially to remove certain banks of hard clay which the natural current was unable, by itself, to erode. Thus today this navigable channel presents a depth of 34 feet (10.35 m), maintains itself without the need of special dredging and is preferred by the large ships, although it is narrower than that of the Southwest Pass—which, by reason of its too great width, permits the current to run tortuously, and thus the banks and shoals continuously form and reform and must then be removed by the continuous labor of the dredgers.

EUROPEAN EXPERIENCE.

The results set forth by Dr. Corthell coincide exactly with the experience of European, and especially that of the Italian, engineers.

Access to the port of Rotterdam is given by the new mouth of the Maas at the Hook of Holland, which has recently been provided with two jetties. This channel, however,—because the jetties are insufficiently extended into the sea, because they are insufficiently elevated above high tide, and because they are too widely separated with respect to the amount of water in the river and the amount which ebbs and flows by tidal movement—is subject to filling up. It was therefore found necessary to build a new auxiliary inner jetty, in order to restrict the section of the navigable channel, thus increasing the velocity of the current and rendering it more effective for scouring the channel. Notwithstanding this restriction, it is often necessary to aid in the work with dredgers, in order to remove the material which is borne by the river and also that which the waves of the sea, scouring from the adjacent shores and breaking over the low walls, deposit in the channel.

At Port Saïd, likewise, the jetties—although originally carried out to a depth of about 8 meters (26.2 feet) and therefore sufficient for the needs of the navigation of the Suez Canal during the past years—soon became, in large part, obstructed by reason of the rapid extension of the beach, subject to the deposits from the neighboring muddy Nile. Recourse was therefore had, from the first, to energetic excavation by means of the most powerful dredgers. However, in the present need of deepening the canal entrance to 12 meters (39.4 feet), it was decided that it would be preferable to prolong the jetties by some 2500 meters (8200 feet), that is, to a depth of about 10 meters (32.8 feet), and then under the protection of these to dredge the bottom to the desired depth of 12 meters (39.4 feet).

In this manner, by the prolongation of the jetties to a point beyond the neutral line—which Cornaglia fixes for the Mediterranean between the depths of 8 and 9 meters (26.2 to 29.5 feet),*

* See Cornaglia "Il Regime Delle Spiaggie e la Regolarizzazione dei Porti", Turin-Pavia, 1891: and also by the same author, "Le Flot de Fond dans les Liquides", Annales des Ponts et Chaussées, Paris, 1881. In the library of the Institution of Civil Engineers of London there is preserved at the wish of the lamented Cornaglia the text of the English translation of this work, which is, however, as yet unpublished, and which it would be most useful to diffuse, in order to throw light on this question.

that is, out to the zone where the action of the inverse bottom surge, or undertow, dominates over that of the direct bottom surge, the sandy material instead of being thrown by the latter into the channel between the two jetties would be carried rather toward the open sea, into deeper water, and thus there would be no silting up of the channel, or it would be reduced to a very inconsiderable amount.

The hope has been entertained that in this manner and with the aid of the mass of water which the tide—although only about one foot in height—renews every six hours in the immense lagoon of Menzabh, there will be less silting up, and such obstruction as may occur will be readily removed by means of dredgers.

ITALIAN EXPERIENCE.

The Italian experiences in the Port of Ravenna and in those of Malamocco and of Lido at Venice give assurance that these hopes will be realized.

(a) Port Channel of Ravenna.

At Ravenna the two jetties were carried out to a water depth of 5 meters (16.4 feet), thus guiding across the bar or coast-line the mass of water which is renewed as a result of tidal movement in the neighboring lagoons, called "pialasse", which have altogether an area of 1366 hectares (5.27 sq. miles). The height of the tide varies from 0.3 meter (0.98 foot) at neap tide to 0.7 meter (2.3 feet) at spring tide, and exceptionally reaches 1 meter (3.28 feet) with the equinoctial tides or with strong and persistent storms with wind from the S. E., which, blowing almost along the axis of the Adriatic, causes a piling up of the water toward Ravenna and Venice and thus gives rise to these exceptional tides.

With these conditions, the mass of water which passes alternately over the bar every six hours, guided by the jetties, varies from about 3,500,000 cubic meters (4,500,000 cubic yards) at neap tides to 6,350,000 cubic meters (8,300,000 cubic yards) at spring tides, and still more in case of exceptional tides. Under normal conditions, the amount of water which passes over the bar is, respectively, 157 cubic meters (5535 cu. ft.) per second and 290 cubic meters (10,260 cu. ft.) per second from the neap to

the spring tide. The wetted section of the navigable channel inclosed between the two jetties, 36 meters (118 feet) apart, being 176.1 square meters (1895 sq. ft.) at neap tides and 186.4

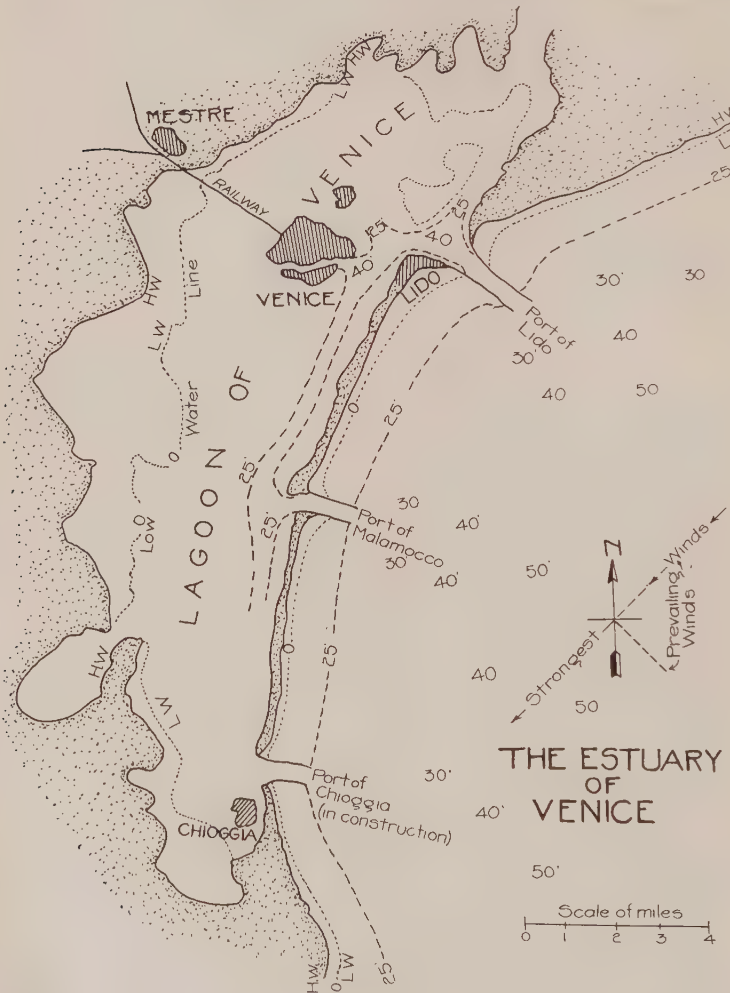

Fig. 1.

square meters (2006 sq. ft.) at spring tides, there results in the channel itself a mean velocity from 0.95 meter (3.12 feet) to 1.47 meters (4.82 feet) per second, which in the time of equi-

noctial tides may reach a velocity of 2.2 meters (7.22 feet) per second when the ebb has its greatest velocity.

As a result, the jetties were hardly completed when the channel scoured itself out, by the action of the tidal currents, to a depth of 5 meters (16.4 feet) on the bar at low water, and has since maintained itself free from sediment without the need of any dredging. Thanks to these jetties, ships of 5 meters draft (16.4 feet) are now frequenting the port of Ravenna.

The only complaint on the part of navigators is that perhaps the section given to the channel is somewhat too small, as a result of which boats manoeuver badly, and, furthermore, the velocity of flow through the channel is very high, making navigation difficult.

At the present time, with the object of carrying the depth of the navigable channel to 7 meters (23 feet) below mean tide, a project has been approved for prolonging the jetties for another 1800 meters (5904 feet), to the contour line 6.5 m. (21.32 feet) below datum. The new reach of channel will be given a width of 42 meters (137.8 feet), in consequence of which the tidal currents will be somewhat less rapid, that is, they will have a velocity of about 1.5 meters (4.92 feet) per second, with benefit to navigation and without injury to the scouring power of the stream to erode and carry away the sand and detritus which the waves of the sea, as above noted, tend to bring and deposit within the channel.

The estimated cost of this new construction is 9,000,000 lire ($1,737,000) for the two jetties and 350,000 lire ($67,550) for the eventual dredging intended in the beginning to aid the scouring effect of the tidal currents and to accelerate its operation.

(b) Port Channels of Venice.

In order to improve the natural channels of approach from the sea to the lagoons of Venice (Fig. 1) (which channels have received the name of *porti canali*), two jetties were built, toward the middle of the last century, at the entrance to the port or passage of Malamocco (Fig. 2) of sufficient length to reach the contour of 8 meters (26.24 feet) depth below datum. The width between the jetties was fixed at 470 meters (1542 feet), in order to guide the mass of water which flows from the lagoon lying within, with an area of 16,370 hectares (63.2 sq. m.) and under the ac-

tion of the tidal movement—which movement varies from 0.4 meter (1.31 feet) at neap tides to 0.72 meter (2.36 feet) at spring tides, and exceptionally to 1.32 meters (4.33 feet) in equinoctial tides when combined with storm winds from the S. E.

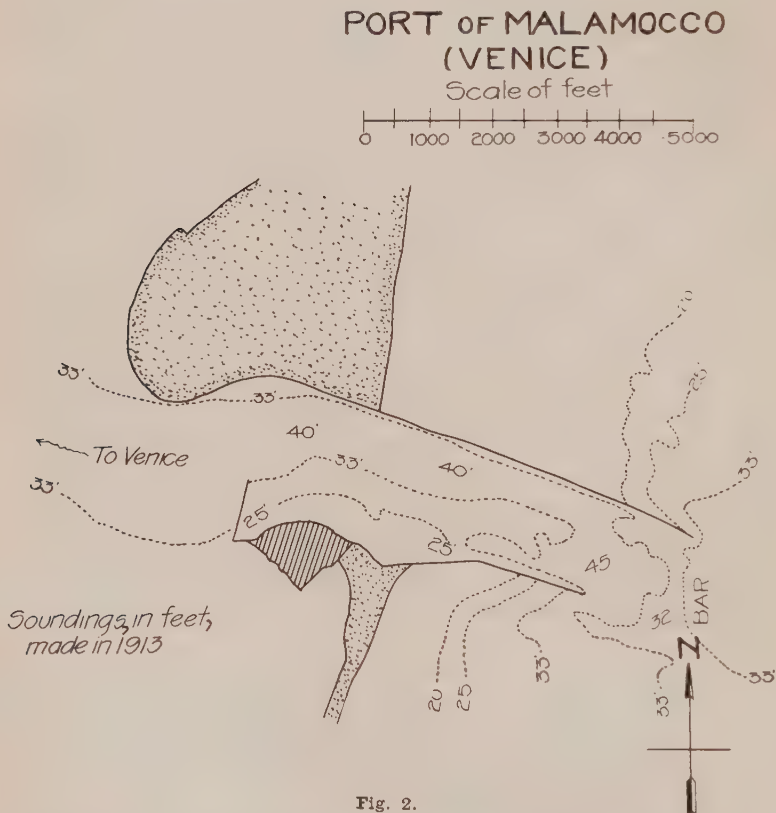

Fig. 2.

With this construction, and without the need of dredging, the bar at the entrance of the channel, which was covered only to a depth of 2 to 3 meters (6.56 to 9.84 feet) at low tide, was carried away by the natural current and the channel now maintains itself automatically at a depth of about 10 meters (32.8 feet) at low tide.

A similar construction was carried out at the Lido entrance (Fig. 3), which gives access more directly from the sea to the

commercial and military harbors of Venice. The lagoon of the Porto di Lido having an area of 29,115 hectares (112.4 sq. mi.), and the tidal movement being similar to that at Malamocco, it was decided to carry the jetties out to the contour 8 meters (26.2 feet) below datum; the width of the channel between the jetties was fixed at 900 meters (2950 feet), with the hope of thus realizing a tidal current with a velocity of 0.6 to 1 meter (1.97 to 3.28 feet) per second from neap to spring tides, which should be sufficiently strong to maintain the channel clear of obstruction and, at the same time, give favorable conditions for navigation, by reason both of the width of channel and of the moderate velocity of current.

The results have been very satisfactory. Before the work was carried out the depth of water on the bar was 2.4 meters (7.87 feet), while at the present time in the channel between the jetties the depth is 8.5 meters (28 feet). However, as a result of the excessive width given to the channel itself, its course is somewhat irregular and tortuous, and certain shoals of sand tend to re-establish themselves. It would have been better to have given to the channel a somewhat reduced width, by building a counter jetty within—as was done at the Hook of Holland in order to correct a similar condition which developed at the mouth of the New Maas, which, as already noted, forms the channel to the port of Rotterdam—otherwise it will be necessary to dredge out these shoals.

It has been decided as preferable, at least for the present, to resort to dredging, as being simpler and cheaper in first cost; in any case, such plan does not compromise the future, as would the construction of a jetty. In any case, it remains a fact that the port of Lido actually offers a depth of 8.4 meters (27.5 feet) at low tide, due solely to the eroding action of the ebb current aided by a small amount of dredging—the purpose of which, it should be said, has been not only to clear away certain shoals of sediment which had formed, but likewise to remove certain old deposits of clay which the tidal currents had not been able to erode, and also certain old wrecks on the Lido bar, which, obstructing the free action of the currents, became centers for the deposit of sediment.

It must be understood that this work of dredging once com-

pleted,—which, as noted, is intended to regulate and unify the work of excavation done spontaneously by the tidal currents—the channel will then have and will maintain spontaneously a depth of about 10 meters (32.8 feet) at low tide.

In view of the excellent results at the port of Malamocco and, likewise, the good results at the Lido, which will soon be still better—since it is now realized that it would have been better to use a somewhat narrower channel between the jetties—the width given to the entrance to the port of Chioggia was determined, rather from the experience at Malamocco than from the experience of Lido. Therefore the proportion was taken between the quantity of water which moves, as a result of the tides, in the two lagoons, respectively, of Malamocco and of Chioggia, and there is thus obtained for the latter port a width of 411 meters (1348 feet) between the jetties, which figure was rounded up to 400 meters (1312 feet). The length of these jetties was made sufficient to reach the contour line 7 meters (23 feet) below datum, and with this arrangement it is hoped to obtain in the navigable channel a depth of about 8 meters (26.2 feet) at low tide. The works are already well advanced and so far point to a complete success; that is, the parallel jetties will be able to guide the tidal currents across the bar and scour it away and prevent any further shoaling up. The authorized cost for this work is 5,700,000 lire ($1,100,100).

The following table gives in résumé the more important characteristics of the works mentioned.

Harbor entrance of	Laguna di Venezia*			Ravenna (Porto Corsini)	
	(1) Malamocco	(2) Lido	(3) Chioggia	(4) Ravenna (Porto Corsini)	(5) Ravenna [In construction in order to obtain a depth of 7 meters (23 feet)]
Period of work	1839-1872	1881-1905	1905-1915	1800-1900	1915-18
Width between jetties, meters	470	900	411	36	42
(feet)	(1,542)	(2,953)	(1,348)	(118)	(138)
Length of north jetty, meters	2,122	N.E. 3,610	N. 1,727	1,165	1,800
(feet)	(6,962)	(11,844)	(5,666)	(3,822)	(5,906)
Length of south jetty, meters	956	S.O. 3,110	S. 1,416	1,315	1,780
(feet)	(3,136)	(10,204)	(4,645)	(4,314)	(5,839)
Area of lagoons, hectares	16,370	29,115	13,175	1,366	1,366
(sq. mi.)	(63.3)	(112.5)	(50.8)	(5.28)	(5.28)
Height of neap tides, meters	0.40	0.40	0.40	0.30	0.30
(feet)	(1.31)	(1.31)	(1.31)	(0.98)	(0.98)
Height of spring tides, meters	0.72	0.72	0.72	0.70	0.70
(feet)	(2.36)	(2.36)	(2.36)	(2.30)	(2.30)
Height of equinoctial tides, meters	1.32	1.32	1.32	1.00	1.00
(feet)	(4.33)	(4.33)	(4.33)	(3.28)	(3.78)
Depth before undertaking work, meters	3.50	2.40	2.40	1.50	5.00
(feet)	(11.5)	(7.9)	(7.9)	(4.9)	(16.4)
Present depth on the outer bar at low tide, meters	9.60	8.60	[in course of execution 7 meters (23 feet)]	5.00	[under design 7 meters (23 feet) is hoped for]
(feet)	(31.5)	(28.2)		(16.4)	
Cost of jetties, lires or francs	8,100,000	8,000,000	5,700,000	3,250,000	9,350,000
(dollars)	(1,560,000)	(1,545,000)	(1,100,000)	(627,500)	(1,805,000)
Annual cost of maintenance, lires or francs	16,000	100,000	....	5,000	....
(dollars)	(3,090)	(19,300)		(965)	

* The mean range of tide at Venice is about 0.56 meter (1.84 feet).

CONCLUSIONS.

The conclusions to which we are brought,—both by the works of Dr. Corthell and by those of Italian engineers,—and which are based on the results of experience so successfully executed for the improvement of the ports of Malamocco and Lido at Venice and of Ravenna, and on which are based the works at the port of Chioggia, now in progress, are the following:

1. In order to improve the navigability of estuaries, it is preferable, in general, to construct jetties which restrict between them and guide to the open sea and beyond the neutral zone the waters of the river or of the lagoon in their movements, especially under tidal influence. For certain special cases, where the construction of jetties may involve an excessive cost or where the bottom may be too unstable, it may be better to depend on dredging.

2. In any case, it should be the aim to improve an existing channel rather than to create a new one and to aid the action of the forces of nature, making the least possible change in their present régime.

3. The jetties should be rectilinear, parallel with each other and bonded carefully into the shore.

4. The orientation of the jetties should be adjusted with due regard for the direction of the prevailing waves and of the tidal currents, in order thus to avoid obstructing, but rather to facilitate, the escape from the estuary of the water and the material held in suspension or eroded from the bottom.

5. The extremities of the jetties should be carried out to the depth of the contour line which corresponds to the depth which it is desired to realize in the navigable channel, and, in any case, they should be carried at least as far as the neutral zone in accordance with the régime of the sea waves at the mouth of the estuary. It may be assumed that such zone in the upper Adriatic, —where the waves may reach a height of about 4 meters (13.1 feet),—will be found between the contours for 5 to 7 meters (16.4 to 23 feet) below datum; in the Mediterranean, where waves are met with to a height of 7 meters (23 feet), the neutral zone will be found between the contours for 8 to 9 meters (26.2 to 29.5

feet) below datum; and in the Atlantic and in other cases with waves still higher, the neutral zone may be found at a depth even exceeding 10 meters (32.8 feet) below datum. However, where the tidal range is great, above 20 feet, the neutral zone is always more inshore and near the 6 to 7 meters (20 to 23 feet) contour line.

6. Where aid is available from a powerful mass of water, as from a large river or from strong tidal currents and especially from large lagoons, in which move alternately great masses of water but slightly turbid, the neutral zone is found in depths sensibly less; hence the jetties need not be carried out so far and the problem receives a still simpler and certain solution. It is well to recall, in this connection, the Venetian saying, "A large lagoon makes a good harbor".

7. The section of the channel between the jetties should have approximately the same area as that found in the reaches of the estuary which lend themselves most effectively to the needs of navigation; and in restricting this area, it should be remembered that the bottom current must attain at least 0.6 meter (2 feet) per second in order to be able to effect any erosive action and to prevent filling up of the channel, while that in the main body of the channel should not sensibly exceed 1 meter (3.3 feet) per second, in order not to interfere with navigation. In case of doubt it is better to adopt a large width between the jetties, with the project in reserve of a further narrowing by means of an auxiliary or inner-jetty, as experience may determine—as at the Hook of Holland—rather than run the risk of giving to the channel too small a section, as at Ravenna, an error which cannot be corrected unless by the removal of one of the jetties, or, otherwise, by the use of auxiliary dredging, as at the Lido at Venice.

8. The jetties should be constructed in such manner as not to permit the percolation of the sand and silt which collect on the outside—a condition which gave much trouble at the old jetties at Port Saïd—and they should be of sufficient height above high tide to prevent ready overtopping by the waves, with the resultant deposition in the channel of the matter which they may carry in suspension.

9. The construction of the jetties should be carried forward with the maximum speed, in order to prevent the reformation of the bar at the outer end in proportion as the jetties advance into deeper water.

10. Due account should be taken of the natural and inevitable development of the shore adjacent to the channel and of the consequent and necessary future prolongation of the jetties.

11. It is useful to aid and to accelerate by means of dredgers, the first work of erosion of the natural currents which run between the jetties, especially for removing possible banks of clay or of conglomerate which the current by itself may not be able to erode. It is further necessary to remove old skeletons of ships which have been wrecked on the bar or on the shoals of the estuary, as were met with at the port of Lido at Venice.

12. It is necessary to watch the channel carefully in the early years, and to correct, with suitable work by dredgers or with the use of fascines, any possible tendency of the current to follow a tortuous path between the jetties.

The conclusions above enumerated are applicable to the generality of estuaries, in order to render them navigable; but there may be very special cases where the traffic is so great and exacting that it may appear, from reasons of finance or of urgency, more expedient—as at Liverpool, New York and Buenos Aires—to depend entirely upon the use of dredgers rather than to face the heavy initial cost of the construction of jetties. Jetties, however, have given very satisfactory results at the South Pass of the Mississippi and at the ports of Malamocco and of Lido at Venice; they demanded a heavy expense for first construction, but have required only slight expenses for subsequent maintenance.

Vice versa, wherever there are great lagoons and the alternative tidal movements have a sufficient importance—as for example at Venice and at Rio Grande do Sul in Brazil, and also at Port Saïd—it would be a grave economic, as well as technical, error not to profit by them; and therefore in such cases preference should be given to the use of jetties, assuming, once for all, the heavy initial cost rather than the continual expense of the incessant annual dredging.

For further information on this subject reference may be made to the following publications:

Monografie sui porti italiani (Monographs on Italian Harbors). Ministero Lavori Pubblici Roma, Roma, 1905.

Commissione pel miglioramento dei porti italiani (Commission for the Improvement of Italian Harbors). Ministero Lavori Pubblici, 3° vol., Roma, 1910.

I Porti italiani (Italian Harbors). Ministero Marina, Roma, 1905.

Mati e Contin—I porti della Laguna Veneta (The Harbors of the Venetian Lagoons). Accademia delle Scienze, Venezia, 1875-85.

Rutazza—Metodo per determinare la larghezza di un porto canale lagunare (Method of determining the width of a harbor lagoon channel). Politecnico, Vol. 28, 1880.

Laroche—Les Ports de la Mediterranée (Harbors of the Mediterranean). Paris, 1885.

Perosini—Il Porto di Malamocco (The Harbor entrance of Malamocco). Venezia, Giornale Genio Civile, 1891.

Torri—Il Porto di Lido (Venezia) [The Harbor entrance of Lido (Venice)]. Giornale Genio Civile, 1901.

Cucchini—Le Port de Lido à Venise (The Harbor entrance of Lido at Venice).

Quinette de Rochemont—Le Port de Venise (The Harbor of Venice). Annales des Pont et chaussées, 1907.

Cucchini—La Laguna di Venezia ed i suoi porti—Conferenze fatte alla Scuola degli Ing. di Padova (The Lagoons of Venice and their Harbor Entrances—Lectures delivered before the School of Engineering at Padua). Giornale Genio Civile, 1912.

Lavori di scavi fatti dalla draga marina "Venezia" nel porto di Lido dal 1909 al 1913 (Work of Excavation accomplished by the Sea Dredge "Venice" at the Harbor mouth of Lido from 1909 to 1913). Giornale Genio Civile, 1914.

DISCUSSION

Mr. M. H. Peck,* Assoc. M. Am. Soc. C. E. (by letter), stated that Dr. Luiggi's paper contains data of much interest, and its conclusions agree in general with American practice as known to him. As in its title the paper claims only the status of "Notes", it is perhaps ungracious to regret that the author did not attempt a logical outline of the principles of design of works for the improvement of navigable estuaries. Mr. Peck.

The only important conclusion of the paper from which Mr. Peck differs (the method of determining areas of cross-section for improve-

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Mr. Peck. ment of channels) is the result of a theory of design which he has developed in the course of several years' experience in dredging estuaries and tidal channels, and of observation and study of regulated channels. A brief statement of his theory will explain his reasons for differing from Dr. Luiggi.

An intelligent design of works for the improvement of any estuary must be based on studies along the following lines:

(1) Character and source of materials forming present obstructions to navigation:

 (a) Upland silt brought directly to bars or banks by upland water.

 (b) Material moved from one part of an estuary to another by tidal, river or wind currents.

 (c) Material moving along the coast, or local material heaped up at the mouth of the estuary by littoral currents or by wave action.

(2) Possible formations of obstructions after improvement:

 (a) By processes similar to those which caused present obstructions.

 (b) Shoaling by processes different from those which caused present obstructions.

(3) Methods of improvement:

 (a) Removal of present obstructions.

 (b) Prevention of accumulation of new material in the improved channel.

The two results striven for (the removal of present obstructions, and the prevention of future obstructions) may be obtained by the same methods or may require the use of different methods. The methods themselves are well known to engineers; and this discussion is confined to an outline of the investigation and reasoning necessary to design a proper cross-section for an improved channel, without consideration of the important question of the alignment of the channel.

1. Character and Source of Materials Forming Present Obstructions to Navigation:

Samples should be taken from the banks or bars to be removed, by boring to the depth of channel required. The character of the material carried or moved by all currents flowing into and in the estuary (whether tidal, upland or wind) also should be determined. A comparative study, thorough or superficial, as the case may require, will show the source of the material to be removed and the manner in which it was brought to place.

2. Possible Formation of Obstructions After Improvement:

Shoals or bars obstructing navigation are formed either by the deposit of material carried in suspension (caused by checking the

velocity of the current) or by stopping the motion of material rolled along the bottom. If the motion of material into or in an estuary and across its mouth is indicated on a contour map of the bottom of the estuary, the conditions under which it will accumulate in the improved channel can be forecasted. The history of improvements made or attempted under similar conditions should, of course, be studied. Mr. Peck.

3. Methods of Improvement:

The character and cause of present and possible future obstructions to navigation being known, all effective methods of removal and prevention should be listed. Methods of prevention fall into two classes —ensuring the passage through the improved channel of all the material coming to it, and cutting off or reducing the amount of material brought to the channel. It is best to consider first methods of preventing the future accumulation of material in the improved channel, as this is the most difficult part of the problem and its solution probably will influence the relative economy of different methods of removing present obstructions.

Experiments made in artificial channels have shown that solids may be moved by a stream in three different ways: in suspension; by rolling or sliding along the bottom; and in a way intermediate between these two, in which the solid particles strike the bottom at intervals and rebound or are carried up by eddy currents between times of striking bottom. The manner of movement of solids carried by a stream depends upon the character of the particles and upon the velocity of the stream. Material carried in suspension will be deposited gradually as the velocity of the stream is checked; and particles sliding, rolling or bounding along the bottom may be stopped either by checking the bottom velocity of the stream (without reference to its average velocity) or by irregularities in the bed of the channel. When tidal currents carry materials into an improved channel, these materials will be more or less completely deposited at slack water—all the materials moving along the bottom will stop and a part of the material in suspension will sink to the bottom. When flow recommences, such material will be put in motion gradually; but as only the surface material is affected and as a higher velocity is required to erode deposited material than to keep the same material in motion, the tidal currents may not be able to remove all the material deposited at slack water. The travel through an improved channel of material brought to it then will depend on (a) the length of periods of slack water or low velocity; (b) the maximum and average velocity of currents; (c) the character and manner of motion of the materials in the channel; (d) the amounts of such materials. As the periods of slack water cannot be changed materially, only the last three items can be affected by improvements.

As stated by the author, if the maximum velocity of currents in a channel intended for navigation exceeds a certain limit (which Mr. Peck would put at about 4.5 rather than 3.3 feet per second), the use-

Mr. Peck. fulness of the channel is decreased. Therefore, if the channel is to be self-maintaining, the heavier materials and excessive amounts of any material must be kept out of it. It would be difficult to determine the safe limits as to character and amounts of material, and impossible to apply the limits in calculation if they could be found. The only guide for action in this direction is a careful examination of local conditions, such as has been outlined.

Material may be kept out of the improved channel either by preventing the picking up of the material by the currents passing through the channel, or by diverting the channel currents carrying undesirable material.

The first method is illustrated by the works for the improvement of the channel at the U. S. Navy Yard, Mare Island, California—shown on the map herewith. In 1902 the controlling depth of the channel between Mare Island and the Vallejo shore was 18 feet, the shoal point being just south of Commission Rock. Investigation showed that at flood tide a current flowed along the west shore of Mare Island toward Carquinez Strait, and that this current carried more silt in suspension than any other current flowing into or from the channel. This silt was the local material of San Pablo Bay, stirred up by the wave action caused by the westerly winds which prevail for ten months in the year.

Accordingly, in 1906, when the system of regulating dykes shown on the map was constructed, Dyke No. 12 was built from the shore out to the angle in the dyke, in order to divert the littoral current into the deeper water of San Pablo Bay and so reduce the amount of silt picked up by the currents. In 1908 the controlling depth in the channel was increased to 20 feet about opposite Dyke No. 8, and the rate of silting had been greatly decreased in the turning-basin near the north end of the Navy Yard opposite Dyke No. 7. However, San Pablo Bay had shoaled back of Dyke No. 12, and in the next two years silting of the section of the turning-basin opposite Dyke No. 7 increased, while erosion continued in the approach channel. Accordingly, in 1912, Dyke No. 12 was lengthened more than 6000 feet, as shown on the map, and by 1913 some erosion took place in the section opposite Dyke No. 7, while the controlling depth in the approach channel was increased to 24 feet. Dyke No. 12 not only diverts into deeper water the flood current from San Pablo Bay to Mare Island, but it also aids in regulating the approach to Carquinez Strait.

The second method (diverting from the channel currents carrying undesirable material) is illustrated by the works designed for the protection of the harbor of Los Angeles, Calif. In 1913 a flood deposited in the harbor between three and four million cubic yards of upland silt, which it was necessary to remove by dredging. Now it is proposed to divert this upland flood-water in such a manner that no upland silt can be brought to the harbor.

Having decided on the desirability of attempting to reduce the

amount of solids brought into the channel, the problem remaining is to determine the velocity required to remove from the improved channel all of the material brought to it and then to decide as to the means necessary to obtain that required velocity. Mr. Peck.

Here the real difficulty is encountered. What is the velocity required to keep the channel clear? Prof. Luiggi says:

> "The bottom current must reach at least 0.6 meter per second in order to be able to exercise any erosive action and to prevent filling-up of the channel, while that in the main body of the channel should not sensibly exceed one meter per second in order not to interfere with navigation".

In "Tidal Rivers", W. H. Wheeler says:

> "Generally, the mean velocity may be taken at 85% of the maximum * * * * it may be taken that the bottom velocity varies from about 75% of the surface velocity for rivers of depths of about 5 ft., to 50% for three times this depth, and 66% for large rivers".

Assuming that the surface velocity is the maximum, for large rivers the bottom velocity would then be 77.5% of the mean; and if the bottom velocity be 2 ft. per second, the mean then will be 2.6 ft. per second. According to Mr. Peck's experience, this mean velocity of 2.6 ft. per second is too low for a tidal channel, while the given maximum of 3.3 ft. per second can be raised safely to 4.5 ft. per second.

The only practical rule given by Prof. Luiggi for the determination of the cross-section is as follows: "The section of the channel between the jetties should have approximately the same area as that found in the branches of the estuary which lend themselves most effectively to the needs of navigation". Existing stable sections in the same material and subject to the same currents undoubtedly furnish the only safe data for the design of improved sections; but the controlling factor is the velocity in the cross-section and not its area. Therefore it may be necessary to take into account the tidal prism between the stable cross-section and that to be improved. Also the stable cross-section may be scoured to hard material, in which case a higher velocity may be permissible than that required to prevent accumulation. Also, the variation in area of stable cross-section between straight reaches and curves must be known, as eddy-effects at curves prevent accumulation at velocities which might permit it in straight reaches; in other words, cross-sections in straight reaches must be smaller than the maximum stable cross-section curves.

Mr. Peck suggests the following outline of work to be done in determining the best cross-section for an improved channel:

1. Plot cross-sections and also surface materials, of stable sections in curves and in straight reaches of the estuary to be improved, choosing when possible those, the soft sides and bottoms of which show that they have the greatest possible area for the local conditions.

Mr. Peck.

2. Make observations of velocities at all stages of an ebb tide of average range, to obtain the average velocities in each cross-section measured in (1), for as many stages of the tide as practicable. Plot curves showing the fall of the tide, the average velocity of the current, the area of cross-section of the current, and the rate of discharge—all in terms of the time element of the tide. Determine the ratio of the maximum rate of discharge to the average rate of discharge, for the full period of ebb-flow and for each observed section.

3. Determine the present tidal prism above each observed cross-section by the tidal area and the average range used in (2).

4. Determine the probable degree of accuracy of the amount of the tidal prisms as found in (3) and calculate higher and lower limits of the probable amounts. Determine the probable degree of accuracy of the velocity observations in (2) and of the areas of cross-sections in (1), and calculate the higher and lower limits of the probable amount of the tidal prisms as found from the discharge curves in (2). The probable amount of any tidal prism may be taken as the mean between the lower of the two higher limits and the higher of the two lower limits.

5. Calculate tidal prisms between the cross-sections considered in (4) by tidal areas and ranges, and check by differences of values found in (4). Adjust differences and find corrected values of tidal prisms at all stable cross-sections. Calculate the tidal prism at any section to be improved by adding to or subtracting from the tidal prism at the nearest stable section, the prism between that section and the one to be improved.

6. For any section to be improved, find from the tidal prism and the period of ebb-flow the average discharge for an ebb-tide having the range observed in (2). From the ratio found in (2) find the maximum rate of discharge for the section under consideration.

7. From the tabulation of data in (2) find the minimum velocity at full ebb required to keep the section under consideration stable. If the stable cross-sections where velocities were measured lie on both curves and straight reaches of the natural channel, it will be practicable to select a velocity from a section the position of which, relative to the alignment of the channel, is similar to that of the section to be improved. If no such section has been observed, special studies must be made. In an estuary studied by him, the velocity in a straight reach was about 13% greater than that in a curve below. On the Brazos River, H. C. Ripley found that the average sectional

area was 13.5% greater in bends than in straight reaches, which should mean that the average velocity in straight reaches was 13.5% greater than in bends. The agreement of these figures possibly is accidental, but in the absence of other data appears acceptable. Mr. Peck.

8. The quotient obtained by dividing the maximum rate of discharge for any section as found in (6) by the required velocity as found in (7) will give the maximum area of cross-section which will be self-maintaining. The depth and width of channel required for navigation being known, a satisfactory cross-section may be chosen. If dredging to the required depth and width of channel does not increase the total area of cross-section beyond the limit found, no regulating works will be required. If the total area exceeds this limit, the area must be reduced by regulating works or the channel probably will silt up again and require periodic dredging. If the area required for navigation exceeds the limit found, periodic dredging will be required.

About a year ago Mr. Peck, at that time in charge of a dredging contract at the U. S. Navy Yard, Mare Island, California, was asked by interested private parties for an opinion on the stability of the channel shown on the map herewith. No funds being available for field-work, the outline given above was followed as closely as the data available permitted; these data included contour maps of the channel, prepared by the Navy Yard at intervals of one to three years, from which stable cross-sections were found; velocity observations made by the Navy Yard at Station 120; Coast and Geodetic Survey chart showing the tidal area above the Navy Yard; and his personal knowledge of the material in Mare Island Strait and San Pablo Bay, and of the results of the investigation of 1902 in the field work of which he had a subordinate part. The results of the investigation seem sufficiently conclusive to warrant the opinion that after the dredging was completed, a depth of 30 feet would be self-maintaining, from near Station 50 to Carquinez Strait—(though probably not for the full dredged width of 600 ft.); and that periodic dredging would be required in the turning-basin between Station 0 and Station 40.

The channel from Carquinez Strait to Station 80 was dredged before March, 1914, and soundings made in May, 1914, showed a self-maintaining channel. Some silting took place between Station 50 and Station 70 (which he considers due to Commission Rock). This was not removed until all other dredging was completed. Material stirred up by the cutter of the suction dredger working in the turning-basin was brought down by the ebb-tide, moved along the bottom of the channel rather than in suspension and was stopped by Commission Rock. He confidently expects that soundings to be made the coming winter will show a 30-foot-deep channel from Station 50 to Carquinez Strait.

Mr. Peck. Soundings taken in May, 1915, show a considerable silting in the turning-basin.

No mention is made by the author of the possible increase in the tidal prism caused by facilitating the inflow of the flood tide. In many cases this would have an important effect; and where any increase in the prism is to be anticipated, care must be taken that the improved cross-section is not unduly restricted.

Mr. Haupt. **Mr. Lewis M. Haupt,*** M. Am. Soc. C. E. (by letter), stated that in responding to the author's request for a discussion, he takes pleasure in calling attention to the excellent results which have been secured in some of the instances named, by the nice adjustment of the parallel jetties to the local requirements; even though limitations of time and space make it impracticable for him to enter upon a thorough discussion of this admirable paper as a whole.

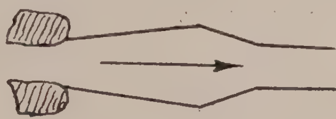
The author calls attention to the failure to secure the desired depths at other localities, where the conditions would seem to be even more favorable; and states frankly the reasons for such failures. He has not given the evolution of some of these instances, due doubtless to lack of information; and yet under "American Experience" he refers specifically to the efforts to secure a 35-foot channel at the Southwest Pass of the Mississippi River, concerning which he reports that the dredging was never able "to obtain the depth of 27 feet (8.2 meters) desired, but only a depth of 20 feet (6.1 meters)". Some of the surveys have shown greater depths, but they were not self-maintaining; because (as stated) "of its great width permitting the current to run tortuously and thus continually to form and reform shoals". However, this Southwest Pass was selected as the most favorable of those in the delta, carrying about 50 percent of the total discharge, widening between self-made banks with easy curves for about 20 miles, having depths of from 40 to 100 feet, and terminating in the inevitable bar at the Gulf with a ruling depth of 10 feet (3 meters).

In 1901 a plan was submitted consisting of two straight, parallel jetties 2000 feet apart, each nearly seven miles long and reaching from the outer slope of the bar straight up the Pass, portions of the work being above water-surface, others in 30-ft. depth of water, and the two jetties estimated to cost \$13,000,000, with annual maintenance charges of \$390,000.

At this time Mr. Haupt was requested to submit a plan for the creation of a channel by controlling the outflow across the bar, and such a plan was submitted guaranteeing a channel of 35-ft. depth, at an expenditure of \$6,000,000. This plan was referred to a Board of Engineers and rejected by it; and it recommended another plan consisting of two jetties of a coffin shape, first divergent, then convergent, and finally parallel over the bar, as in the sketch. This plan would

* Cons. Engr., Cynwyd, Penna.

form a pocket, or *cul-de-sac*, 5000 ft. wide at its broadest part and 3000 ft. wide crossing the bar, while the normal widths in the natural Pass were about 1300 ft. The maintenance was to be done by dredging. The jetties were placed upon the shoalest portions of the mud flats, in order to reduce their cost and to "take from them the duty of forming Mr. Haupt.



the channel". If the jetties failed in their expected action, then spurs were to be built upon their inner faces and the material dredged from the channel pumped upon the interior slopes of the wide enclosure. In this way the Board reduced the estimated cost to $6,000,000, but this reduction was not accompanied by a guarantee of any definite results.

Mr. Haupt then appeared before the Board and indicated by means of a model what would happen under the recommended project. His presentation resulted in a further modification in the plans for the jetties, but the changed plans left them still much too far apart and increased the distance between the outer parallel portions of the jetties to 3500 feet; and this modified project is the one described by the author.

The results from the work as thus constructed were inevitable. The enormous volume of sediment carried gulfward, being checked by the inertia of the heavier sea-water, soon recreated the bar about 3000 feet beyond the extremities of the jetties. Estimates have been made for the extension of the jetties, and unless the capacity of the dredging-plant can be made equal to the detritus fed to the channel, this mechanical contest must go on forever. Had the sustaining jetty been built on a suitable curve of about five miles' radius and had it been properly adjusted, then it would have cast the sediment on the opposite flank, thus building its own automatic self-adjusting levee and creating an ample channel. Such action is typical of many alluvial streams.

Although there are two jetties at Malamocco, the success of the channel would seem to be due less to the two jetties than to the interior spur at the throat, which projects the ebb against the north jetty, thus causing a violent reaction and creating the channel close to that jetty. The south jetty serves to check the ingress of littoral drift, and thus aids in maintaining the channel.

The author concludes his paper by citing some of the facts accompanying the use of two jetties which he appears to think should be "rectilinear, parallel with each other, and tied carefully to the shore formation".

Mr. Haupt.

On the contrary, the two jetties at the South Pass of the Mississippi, as will be those at Swinemunde on the Baltic, are curved and required only a minimum of dredging and have resulted in very little advance of the bars.

It is true that in some localities it may be cheaper to maintain channels by dredging rather than by current regulations, but after some 25 years of experience on the Mersey Bar, England, it is admitted that "dredging has its limitations". The same conclusion will be realized soon in the case of New York harbor entrance when the 60-odd million cubic yards of drift constituting the Jamaica Bar reaches the outer scarp of the New York entrance and enters the Ambrose Channel. The present rate of travel of the Jamaica Bar is a mile in 17 years.

The most remarkable results ever attained in the removal of bars under extremely adverse physical and political conditions were those attained at the Aransas Pass inlet on the Gulf Coast of Texas. Here the mean tidal oscillation is but 14 inches and is diurnal. The proposed channel was secured, however, by a detached reaction-breakwater. This work was decided on in 1887, begun in 1895 under private contract for completion in ten months, and taken over in 1899 by the Government for completion under certain conditions, which, after long delay, were not fulfilled. Yet, notwithstanding these delays and obstacles and before the work was completed, the channel was scoured out by the tidal currents without any dredging whatever and with no advance seaward of the bar.

Mr. Haupt stated that great modifications have been made by the Government since, in order to adhere to its original two-jetty plan; but such modifications merely have impaired the value of the improvement, added largely to its cost, and made necessary the resort to dredging and jetty extension.

The history of the Aransas Pass development remains to be more fully described for the benefit of the profession as the most efficient and natural method of removing ocean bars, and of creating self-maintaining channels.

Dr. Corthell.

Dr. Elmer Lawrence Corthell,* M. Am. Soc. C. E. (by letter), stated that it is a great satisfaction to him to have his views confirmed so definitely and fully by such an eminent and experienced harbor engineer as Comm. Luiggi, with whom he is quite intimately acquainted and of whose great ability, skill and experience he knows personally. He found nothing to criticise in the paper as he took issue with nothing in it; but he wishes to allude to some details so as to clarify them and bring them down to the present moment, and also to make some minor additions.

The author states that, "notwithstanding the fact that though for many years past and for many estuaries these problems have been treated by various means and in a more or less satisfactory manner,

* Cons. Engr., New York, N. Y.

the true solution is still the subject of doubt and of controversy among engineers of river and harbor works''. The difficulty has been that erroneous assumptions have led to wrong bases for construction, and consequently to disappointment in results. Dr. Corthell.

The author states some of these faults in a generous manner. His paper divests the problem of misleading assumptions and, with its conclusions based on actual experience, ought to lead to a simplification and better understanding of such problems.

In the discussion of the dredging method, the author refers to the Mersey, the Clyde and Scheldt. He refers also to the Rio de la Plata and to the bar at the mouth of the Hudson, as illustrative of satisfactory results by dredging. However, it may be questioned if in the cases of these great ports it has been found in every instance to be the wisest plan to dredge, without using confining and regulating works. Dr. Corthell affirms nothing on this point, but calls attention to some facts for consideration.

This year's Annual Report of the Engineer-in-Chief of the Mersey Docks and Harbor Board states that during this last year there were dredged from the channels leading to the sea about 10,000,000 cubic yards of material to maintain the channel, and that since the commencement of dredging in 1890, the enormous amount of about 156,000,000 cubic yards has been dredged in these channels, and that the process of silting still goes on. The vast fleet of this most powerful dredging plant (probably the largest combined plant in the world) is barely able to maintain with great cost and difficulty the channels for the deep-draft ships that pass through them,—and much less to further deepen them.

Some years ago the very strong currents heavily loaded with sediment evinced a serious inclination toward changing the direction of the dredged channel at one or two points, and the engineers were obliged to introduce a heavy guiding-wall of rubble stone, called ''revetment'', which extends from ''5 feet above bay datum'' down to the bottom of the deep channel. This is really the beginning of controlling-works or jetties. The question may be asked, Would it not have been wiser a quarter of a century ago to have laid out a channel from the deep waters in the estuary to the deep waters outside, and then assisted the currents to deepen this channel by auxiliary dredging, instead of relying entirely upon dredging to create and maintain this important navigation channel?

The hydraulic conditions at the Liverpool estuary (the mouth of the small river Mersey) are quite unique, and the hydraulic forces and the transported sediments are of great magnitude. Above Liverpool is an extensive tidal basin. The range of the tides is very considerable and the tide inflow into this basin and its outlet from it bulks very large in volumes of water and sediment brought in and sent out twice each 24 hours.

Dr. Corthell. The capacity of this estuary-area is about 73,000,000 cubic yards of water, and the tidal current brings in from the outlying shoals and bars probably nearly 200,000 cubic yards of solid matter. This water and this sediment move in and out twice daily—sometimes greater and sometimes less in amount, dependent mainly upon the varying amplitude of the tides. The "fretting" (scouring) process in the tidal basin above Liverpool, and the increment of sediment from the watershed of the River Mersey, make many changes and tend to decrease the capacity of the tidal basin. As generally is the case, these conditions produce an extension of the outer bar seaward. In the half century prior to the year 1884, the outer contour lines of deepest channel advanced about 2000 yards, or at an average rate of about 120 feet per annum. Dr. Corthell has been and is of the opinion that serious consideration should be given to the question of fixing the bar and Queens and Crosby channels permanently by guiding and protecting dykes or jetties, instead of relying entirely upon constant dredging, as is the practice.

The conditions in the Clyde are very materially different. It is a small, narrow river with a hard material in the bottom and very little movement of detritus, conditions which make dredging the only means of ameliorating the navigation conditions. At New York also the conditions are very different from those at Liverpool; the tidal amplitude at the former being only about 4½ feet and the material in the outer bar being quite coarse and not easily moved by the tides—with the shores separated widely and the conditions suitable for a dredging process of the proper kind.

The first great suction dredges used at New York were modelled after the Liverpool hydraulic dredges and were a failure. This was because they were designed to dredge while anchored, as at Liverpool, where the loose, fine material easily flows to the suction-head of the inlet-pipe. At the Ambrose Channel, the suction-head sank down into the hard sand; but the material did not flow to it and left the surface full of holes like a pepper box, causing failure, disappointment and great financial loss to the contractor.

Again, the conditions at the estuary of the Rio de la Plata are peculiar. At the head of it, where the combined volumes of the Parana and Uruguay enter it, the estuary is several miles wide; above Buenos Aires, ten to twelve miles wide, increasing to thirty miles; and at the Punto Indio Bar, sixty miles wide.

At Martin Garcia, near the head of the estuary, originally there was a long, shallow channel of about 14 feet depth. This was fully buoyed and lighted so as to compel all the steamers to take the laid-out channel, one purpose being to make the steamers do the dredging, moving as they did in the line of predominating outward current. This process, by which the propellers stirred up the bottom of the estuary, has resulted in an increased depth of from four to five feet. At the Punto

Indio Bar (lying in the track of all steamers plying between Montevideo and Buenos Aires, and 24 miles wide between 24-foot contour lines and with an average depth of only 19 feet on the top of the soft mud) the steamers pushed their way through 2 or 3 feet of this soft mud. Dr. Corthell.

Dr. Corthell (who in 1900-1902 was the Consulting Engineer of the Argentine Government on all its hydraulic and port works) advised the Government to adopt the same plan as that so successfully carried out at Martin Garcia; and the plan was adopted. Careful and extensive observations were made to ascertain the material composing the bar and the direction of the predominant currents, a work of some engineering difficulty in a river 60 miles wide. The material was found to have a normal slope in position of 1 in 500, being practically a semi-fluid mass. The course adopted was buoyed with luminous buoys and with several lightships, presenting a clearly marked course both by day and by night. The steamers, which formerly had each travelled in its own chosen, haphazard direction, immediately began to follow the clearly marked course, with a resultant increase in depth of 2 or more feet within two years. Then to develop the channel further, powerful suction-dredges were put in it. Manifestly no other plan was practicable under the conditions.

At the entrance channel of the port of Buenos Aires the conditions were very different. Before the port was built, with its various basins in the fore-shore, there was a very flat slope out to the anchorage of vessels 12 miles distant. Channels 100 meters wide were dredged through this shoal to the northern and southern entrances of the new port. These channels have required and still require an immense amount of dredging; as the current of the river (usually heavily charged with sediment from the great Parana River, 40% larger than the Mississippi River in annual volume of discharge) crosses the dredged channels at a small angle.

Dr. Corthell, under instructions from the Minister of Public Works to design an enlargement of the port, to be ample for half a century, in connection with this enlargement proposed to build permanent mattress dykes on each side of the entrance channels, mainly to prevent the continual deposit of sediment in the entrance channels, but also to get some advantage from the tidal currents. His plan as yet has not been approved by the Government, but he still believes that a combination of protecting and guiding works in connection with dredging is the correct plan to adopt at this important port, the business of which has increased from a tonnage of entrances and clearances of 650,000 tons in 1885 up to 10,000,000 tons at the present time.

Comm. Luiggi gives much space to the operations at the mouth of the Mississippi River and states as follows, referring to the argument of the advantages of dredging: "To this (the success of jetties at the mouth of the South Pass of the Mississippi River) the partisans of the dredging system observe that entirely similar works carried out at the Southwest Pass of the same Mississippi River have failed to give satisfactory results". The author then proceeds to explain the difference

Dr. Corthell. between the plans of the works at the two mouths of the river, but Dr. Corthell wished to supplement his statements and to bring the history down to the present time.

The fact is that the works at the Southwest Pass of the Mississippi were not designed as jetties, but the improvement was a dredging plan pure and simple. The jetties, if they could be called so, were intended simply to protect a channel to be obtained by dredging. Therefore this case cannot be referred to as an argument against the jetty plan and in favor of dredging; and the failure to give satisfactory results is a failure of the dredging plan, not of jettying.

The commission of engineers authorized by the United States Congress did away with the parallel jetties which Dr. Corthell had proposed seven years earlier and which a board of government engineers had proposed a year before. The commission, in order to reduce the cost of the improvements, laid out its dykes along the shoals on either side of the outlet where the water was the shoalest and terminated them in shallow water at the outer edge of the sea-bar. These dykes were 7000 feet apart at one point, and at the sea ends the commission placed them 3000 feet apart; while Dr. Corthell had proposed a uniform distance apart of about 2000 feet effective width. The works proposed by the commission were not to be brought above the surface of the water; and instead of being designed with their sea ends at right angles to the littoral current, they were to be built at the acute angle of 30 degrees.

The principles on which the commission's plans were based are exactly the reverse of those laid down by Comm. Luiggi in his "Conclusions". Instead of permanent works located to create the channel, with dredging as an auxiliary when necessary, the commission proposed to create the channel mainly by dredging and to protect it by these outlying works from deposit of sand from the outside. The commission estimated that 22,000,000 cubic yards of material would have to be removed (two thirds of it by dredging) to make the channel required by Congress, which was to be 35 feet deep at mean low-water and 1000 feet wide at that depth. Afterwards the plans were modified somewhat by the War Department, but not materially. The works were begun in December, 1903, and completed in 1908. The results may be epitomized as follows:

Up to June 30, 1915, there had been removed by dredging a total of 28,000,000 cubic yards, instead of the 15,000,000 cubic yards proposed. In the spring of 1915, seven years after the works were completed, there was at one time a controlling depth of only 25 feet; since July, 1912, the channel depth has varied from 25 feet to 32 feet; and as late as August 1, 1915, the controlling depth was only 25 feet. A narrow channel 30 feet deep usually can be found maintained by dredging.

Turning now to the small South Pass, where the channel was created by permanent parallel jetties and where during the development of the channel only 1% of the material removed was taken out by dredges to

hasten the development and to handle refractory material, there is now (36 years after the full channel was obtained in 1879) a least depth of 34 feet; a wide, straight and uniform navigable channel with no shoals outside in the sea; and the works never have been extended seaward since they were laid out by Dr. Corthell in 1875. In the year 1914, 71 percent of all steamships trading at New Orleans drawing over 25 feet used the South Pass. Dr. Corthell.

The above facts are pertinent to the general subject and fully support the contentions of Comm. Luiggi as expressed in his "Conclusions".

There is an important point brought out in the facts about the various works described in the author's paper. Reference is made to the extensive width between jetties at the mouth of the Maas (Hook of Holland) and at the Lido Channel in the Lagoon at Venice. As a general rule, whenever the width is too great, dredging has to be used to remove deposits in the channel, which the feeble currents cannot remove because of the extensive width. At the mouth of the Maas this feature was illustrated fully in Dr. Corthell's paper on "Rotterdam to the Sea" presented to the International Navigation Congress at The Hague in 1894.

The distinguished author of the Maas project, Mr. Caland, was possessed of the idea that rivers, especially tidal rivers, grow wider naturally as they approach the sea, therefore he made his artificial cut through the Hook of Holland and his channel in the sea to conform to this assumed requirement; later he was compelled to acquiesce in the recommendation of a board of engineers called to investigate the project, to narrow the channel 200 meters, and (as Comm. Luiggi points out) even this narrowing was not sufficient.

This excessive width of channel also is the fault at Lido, as Dr. Corthell saw on his examination of these works a few years ago. The lesson taught by the faulty layout at Lido has been made use of in laying out the works at Chioggia, where the width is 1312 feet instead of 2950 feet as at Lido.

Recently there has been a controversy about the width to be made between jetties at the Barra of Rio Grande do Sul, Brazil. Dr. Corthell, under his concession from the Brazilian Government, designed the width between jetties to be 750 meters; but an international board of prominent engineers has voted in favor of a width of 1000 meters. Fortunately the council of the French company now holding the concession would not approve the recommendation for the wider channel and has adopted a width of 725 meters.

In works over bars at the mouths of rivers and tidal inlets, another important requirement for success is rapidity of construction. Dr. Corthell attributes complete success at the South Pass of the Mississippi River, in part to the speed with which the works were constructed. Dilatory methods and too great width of channel generally cause a very

Dr. Corthell. troublesome extension of the outer face of the bar. Three examples are cited to prove the correctness of these statements, as follows:

1: At the mouth of the Southwest Pass of the Mississippi, where the jetties now are being extended in an endeavor to overtake the advance of the outer face of the bar—which at the 35-foot contour depth has advanced over 3800 feet in the last ten years.

2: At the mouth of the Rhone River, where a layout of dykes very similar to that of the Southwest Pass resulted in a great extension of the bar, in an absolute failure to achieve any useful result, and in the abandonment of the project; and where instead the St. Louis Canal was constructed to give a lateral outlet with locks into an outlying bay.

3: At the Bara of Rio Grande do Sul, where instead of parallel jetties a proper distance apart, a funnel-shaped outlet and too wide an opening were used; which faulty plan, coupled with extreme slowness of advancement of the works, pushed out the sea contours six tenths of a mile and required very costly work to meet the conditions in a seaway exposed to the storm waves and swells of the South Atlantic.

Finally, in view of the peculiar and even unique character of the bar works, and in view of the partial or entire failures which have occurred, it does not seem misplaced to recommend that engineers accepting positions in charge of such works, but inexperienced in this special class, would do well to insist (however eminent and experienced they may be in other kinds of engineering) that there should be associated with them in consultation an engineer who has had personal and varied experience in work of this class. When thus called in, the counsel of the expert should be followed and adhered to and it should be understood by all that there must be no departure during the construction from the advice of the expert selected.

Dr. Corthell gives this advice earnestly, after 47 years of practical experience with rivers and mouths of rivers of varying character and after examination and study of about 75 rivers, harbors and ports of many countries. This advice is given hesitatingly but from a sense of duty. He knows that it will be read by engineers who, in many kinds of civil engineering work, have a much wider experience than himself; but he feels safe in saying that in this particular kind of work no one, to his knowledge, surpasses him in practical experience, even though they may far excel him in general engineering knowledge, skill and experience.

Paper No. 33

ON THE RIVER IMPROVEMENT WORKS IN JAPAN, WITH SPECIAL REFERENCE TO THE RIVER YODO.

By

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AN OUTLINE OF THE RIVER IMPROVEMENT WORKS IN JAPAN.

The Empire of Japan consists of the Mainland (Honshû), Kyûshû, Shikoku, Hokkaido and other islands and the peninsulas, Karafuto (Japanese Sakhalin) and Korea. Of these, Hokkaido, the Mainland, Shikoku and Kyûshû lie between 31° and 45° N. lat. and 130° and 145° E. long., the greater part of the land being thus situated in the temperate zone; its climate is mild and healthful. The Mainland is a narrow island extending from the north-east to the south-west, with a mountain ridge running through the middle and forming the water-shed. The rivers of this island, therefore, run north and south, and are mostly short and torrential. None of them is long and winding like the rivers of continental countries, and they somewhat resemble those of Switzerland, which start from the Alps and run into the lakes below. The rivers of Hokkaido, Kyûshû and Shikoku are no exceptions.

Though the sources of Japanese rivers are generally wooded, the soil being of an impermeable nature, the ratio of discharge to rainfall is very high; and as the mountains are very steep, the velocity with which the rain runs down is great. Moreover, if we study our river courses minutely, we see that while the mountains are high and steep and the sea is near, the level land is very flat and the table-land between the mountains and level land is very scanty, so that the rivers, as soon as they emerge from mountainous regions, are suddenly cast upon flat lowland; consequently, their volumes of discharge are so much increased that,

unless large breadths are allowed to the water-courses and strong embankments are built, inundation is apt to occur. As a matter of fact, the sections of rivers not improved by modern engineering are very insufficient; consequently the streams often break through the banks, and when they do so they generally inundate nearly the whole of the level land, which, as we have said, is very flat.

The average annual rainfall in Tokyo, according to statistics for the 10 years, 1901-1910, was 1608 millimetres (63.4 ins.) and the greatest daily rainfall in the same period was 165 millimetres (6.5 ins.). These figures represent the amount of rain in the flat districts of Central Japan, and the figures for the districts further south which bear the brunt of storms proceeding in north-eastern directions are much larger. Thus the maximum annual rainfall at Ikawa in Shizuoka Prefecture (640 meters [2100 f.] above the sea-level) was 4503 millimetres (177.5 ins.) in the same period of years, and at Odaigahara in Nara Prefecture (1566 metres [5150 f.] above the sea-level) 4298 millimetres (169.2 ins.), while the maximum daily rainfall in the latter place was 688 millimetres (27.1 ins.) and 547 millimetres (21.6 ins.) at Nasé in Kagoshima Prefecture (4 metres [13.1 f.] above the sea-level). In mountainous regions a rainfall of 300 millimetres (11.8 ins.) in a day is not rare. As a rule a rainfall of 200 millimetres (7.9 ins.) in the source of a river causes more or less flood in the lower stream. In 1910, from 900 to 1200 millimetres (35.4-47.2 ins.) of rain fell in five days—a greater part of it in three consecutive days—in the source of the Arakawa, which flows through Tokyo, and the result was a flood unprecedented in the history of the city.

In Japan, rain is most plentiful in June, July, August and September, and from the beginning of June to the beginning of July it rains almost every day, the season being known as Tsuyu. But the rains which bring on floods generally accompany storms which invade the land from the south-west about the months of August and September. These rains are especially apt to cause deluge when they come after many wet days, as the soil is already saturated with water.

The following is a list of the drainage-areas of some of the Japanese rivers and their greatest discharges as adopted in the improvement designs. We give it to show the greatness of the

discharges of Japanese rivers in comparison with their drainage basins. Unless otherwise stated, the figures for the drainage areas represent the total drainage areas of the rivers, and those for the discharges represent the discharges of the lower streams in the level land, where improvement works are carried out, so that they may be regarded as showing the flow of the water coming from the entire drainage-basins.

Name of River	Drainage Area (square miles)		Length of Main River (st. miles)		Maximum Discharge (cubic feet per second)	
	Sq. Mi.	Sq. Km.	M.	Km.	C. F. S.	(C. M. S.)
Chikugo	1110	(2880)	86	(138.4)	160,000	(4531)
Kiso	2040	(5290)	142	(228.8)	264,000	(7460)
Ibi	600	(1550)	67	(107.8)	150,000	(4248)
Nagara	900	(2330)	74	(119.1)	150,000	(4248)
Sho	732	(1895)	89	(143.2)	130,000	(3681)
Kuzuryû	996	(2580)	70	(112.6)	150,000	(4248)
Yodo	3270	(8460)	96	(154.5)	200,000	(5663)
Tone	6132	(15,880)	197	(317.5)	200,000	(5663)
Ara	1200	(3110)	110	(177.1)	150,000	(4248)
Watarase	978	(2535)	65	(104.6)	90,000	(2548)
Kitakami*	3270	(8460)	149	(240.0)	200,000	(5663)
Shinano†	4086	(10,590)	226	(364.0)	200,000	(5663)
Yoshino	1422	(3200)	144	(232.0)	500,000	(14,160)
Takahashi	966	(2500)	67	(107.8)	250,000	(7080)
Onga	426	(960)	38	(61.1)	150,000	(4248)

We have already explained the physical configuration of the country, the condition of its rivers, and its great rainfalls. All these unite to swell the discharge of rivers, and their sections being in most cases insufficient, inundation takes place almost every year. The floods not only damage embankments, flood fields, wash away houses and crops; but also impede traffic, injure the public health and cause many other indirect losses. From time immemorial Japan has been called Mizu-ho no kuni (the Land of Lucky Rice-ears) and its paddy-fields have been the pride of the nation, yet there is no denying that it is at the same time the land most subject to floods on the face of the earth.

* Discharge observed at the point 20 miles (32.2 Km.) above the mouth and the drainage area is that of the river down to that point.

† Discharge observed at the point 35 miles (56.3 Km.) above the mouth and the drainage area is that of the stream down to that point.

Such being the case, special attention has been paid to the improvement of rivers. In the present system, works of local natures are entrusted to the control of respective prefectural offices or lower administrative bodies, but those that concern two or more prefectures or entail large expenses or those that require to be conducted under a systematic design on great scales are controlled by the Central Government. Among the rivers named above, improvements have already been effected on the Chikugo, the Kiso (with its tributaries, Ibi and Nagara), the Shô, Kuzuryû, Yodo, and the lower portion of the Tone.

An extensive plan for the improvement of rivers was drawn up in 1911. Sixty-five important rivers were selected, and it was decided that the State should improve them in two periods. In the first period, works on twenty important rivers, including those that the State then had in hand, were to be executed, and the other forty-five were to be improved in the second period which was to follow immediately. For the first period, which was to extend over eighteen years, a sum of 82,500,000 dollars* was appropriated. Among the rivers of the first period, those on which works are now being executed are the Tone, the Ara, the Watarase, the lower portion of the Yodo, the Yoshino, the Takahashi, the upper portion of the Kuzuryû, the Onga, the Shinano, and the Kitakami; their estimated cost and the amounts of work completed up to April, 1914, are as follows:

Name of River	Cost of Works (Dollars)	Amount completed up to April 1914	Amount to be completed
Tone	17,778,408.743	9,701,872.740	8,076,536.003
Ara	6,000,000.000	3,208,188.320	2,791,811.680
Watarase	3,750,000.000	1,828,223.555	1,921,776.445
Yodo	1,500,000.000	992,879.323	507,120.677
Yoshino	4,000,000.000	1,796,800.600	2,203,199.400
Takahashi	2,391,685.000	1,127,158.888	1,264,526.112
Kuzuryû	2,255,605.000	1,974,414.947	281,190.053
Onga	2,197,500.000	1,804,468.280	393,031.720
Shinano	6,500,000.000	3,111,209.069	3,388,790.931
Kitakami	4,000,000.000	1,042,948.649	2,957,051.351
Totals	50,373,198.743	26,588,164.371	23,785,034.372

* Converted into U. S. Dollars at the rate of 2 yen to a dollar.

The foregoing is a general sketch of the river improvement works in Japan, and in the following pages we will give the details of the works on the Yodo, in order to give the reader a notion of the river improvement works in Japan.

THE IMPROVEMENT WORKS ON THE RIVER YODO.

Introduction.

The River Yodo, which emerges from Lake Biwa and flows past the districts near Kyoto, the old capital of Japan, and, on its lower course, through Osaka, the commercial centre of the country, is well and widely known. The river has on its banks many noted places, extensive cultivated fields, and has afforded from ancient times facilities for navigation, irrigation and drainage. It is also rich in hydraulic power. But formerly when the river overflowed its banks, not merely the cultivated land but the prosperous city of Osaka itself was left to the tender mercies of the flood. With a view, therefore, to prevent this evil, the Government early inquired into the affair. In 1896, the undertaking was approved by the Diet and the improvement works were embarked upon, to be completed in ten years. There occurring, however, need of supplementary works, and the main works themselves being impeded by the influence of the last war, the term of execution was prolonged, and in 1910, after fifteen years from the outset, the works were completed. The total cost of construction amounted to $5,031,000. An account of the design and execution will be given in the following pages.

The Drainage Area and the River-Course.

The drainage area of the River Yodo covers 3270 square miles (8460 sq. km.), of which about 490,000 acres (198,300 hectares) (i. e., 23 per cent of the total drainage area) are cultivated and inhabited land.

The designation "Yodo" does not apply to every part of the river, but only to the course below the town of Yodo. Above the town, the river is known as the "Uji", while the upper stream, as it emerges from Lake Biwa, is called the "Seta", named most probably from the town of the same appellation.

For about five miles after it starts from the lake and as it flows south, the river is gentle, and boats may ply up and down the stream. Then turning into a rapid it rushes down among

mountains, and after much meandering comes to the town of Uji, whence downward it passes through a flat country, with embankments on both sides. The river gradually widens, and the force of the current becoming less, the river is again navigable. When it reaches Fusimi, the current is slow and facilities for water transportation are very great. Thence the river flows, generally speaking, in a south-westerly direction, passes through Osaka and runs into the sea. Near the mouth the river is known as the Aji. From the outlet of the lake to the mouth, the river is fifty miles (80 km.) in length.

In order to show the nature of the river course, the slopes at low-water are given below:

	Length in miles M. (Km.)	Fall per 1000
Mouth of river up to Fusimi	31.53 (50.6)	0.2–0.374
Fusimi up to Uji	3.66 (5.9)	0.424
Uji up to water gauge at Toriigawa	14.40 (23.2)	3.032

The water gauge at Toriigawa is situated at a point 3/5 of a mile (0.97 km.) below the outlet of the lake, and its readings are supposed to represent the level of the lake. The slope from the water gauge to Uji is more minutely divided as follows:

	Distance in miles M. (Km.)	Fall per 1000
Toriigawa to Sencho	2.44 (3.9)	0.210
Sencho to Sekinotu	1.22 (1.97)	1.164
Sekinotu to Sisitobi	1.22 (1.97)	3.464
Sisitobi to Uji	9.76 (15.7)	3.912

The most important portion of the river for navigation is the distance of 30.5 miles (49.1 km.) between Osaka and Fusimi, and on the banks for this portion there are many noted towns, such as Yodo, Yamazaki, Hasimoto, Hirakata, etc. The traffic on the river is extremely busy; besides, the river is connected by a canal with Kyoto and the towns on the shore of Lake Biwa.

There being, as we have seen, a considerable fall between the lake and Uji, the river has already been utilized by the

Kyoto Canal and the Uji Hydroelectric Company, which obtain hydroelectric power to the amount of 50,000 hp.

The most important of the affluents are the Katura and the Kizu. The former joins the main stream from the right side a little below Yodo, while the latter joins it from the left side near Yawata, two miles (3.2 km.) further below. The Kanzaki and the Nakatu are the largest of the streams that branch out from the main river. The former departs from the main stream at five miles (8.1 km.) above Osaka, and the latter just above Osaka, the departure taking place on the right side in either case. Towards the end of the course the river bifurcates, one stream being called the Dôjima and the other the Tosabori. They again join into one, and when the Kizu (another river of the same name) branches off a little below, the main stream assumes the name of Aji and flows into Osaka Bay.

Flood Damages.

Of the whole water-basin of the River Yodo, the districts that suffer most from floods are the plains of Settu and Kawachi; then come the flat districts around Lake Biwa, and finally the plain of Yamasiro. (See Plate II.) The total flooded area is estimated at 100,940 acres (40,880 hectares), which is about 50 per cent of the whole cultivated fields of the flat country around the lake and along the main stream. The flooded area may be divided as follows:

The plains of Settu and Kawachi..........	49,735 acres (20,150 hectares)
The districts around the lake..................	29,155 acres (11,800 hectares)
The plain of Yamasiro..........................	22,050 acres (8,950 hectares)

Damages done to the districts around the lake come from the rising of the water of the lake and its long duration. According to observations made at Toriigawa since 1874, the normal lake water-level is 2 ft. 9 in. (0.815 m.) by the water-gauge there, and whenever the water-level rises above it, a flood is the result. A year rarely passes by without experiencing a flood in a greater or less degree. It comes usually between spring and early autumn. According to the result of investigations, the rise of water exceeding three feet (0.915 m.) above the normal lake-level is not uncommon, but the rise exceeding six feet (1.83 m.) above the normal level must be regarded as exceptional. In 1885, the flood fluctuated between four and six

Plate I. (Scale 1:1,000,000.)

feet (1.22-1.83 m.) in April, May and June, and on July 4th it rose to the height of 8 ft. 11½ in. (2.73 m.), devastating in consequence 29,400 acres (11,900 hectares) of cultivated land around the lake and submerging a great many houses. This is an instance of "extraordinary flood". The case was similar in

the flood of 1892, only the highest flood level recorded was 3 ft. 6 in. (1.07 m.) lower than that of 1885. The flooded district, accordingly, appears to have been only 17,150 acres (6950 hectares). This is an instance of ''ordinary floods''. The flood of 1896 showed the highest level, 12 ft. 4 in. (3.76 m.)—3 ft. 4 in. (1.01 m.) higher than that of 1885. The damaged area was, of course, far larger.

Damages on the districts around the lake are greatly increased when the high flood-level continues long or the flood subsides slowly. The duration of floods varies between several weeks and several months, and the harm done to the crops can not be exaggerated. Extraordinary floods, such as that of 1885, come once in ten years, but an ordinary flood occurs at least once in three years, and the people suffer most from it.

Damages inflicted upon the water-basin of the River Yodo, i. e., the plains of Yamasiro, Settu, and Kawachi, differ from those caused by the overflowing of the lake. They are of two kinds: the damages caused (1) by the breach of the embankments and (2) by the insufficient drainage.

The breaching of an embankment results in the inundation of the whole adjacent country, and besides devastating land, crops, and houses, it further involves casualties among men and beasts. This is indeed the worst of all the evils arising from floods. To cite an instance: in 1885, the embankment at a point near Hirakata gave way and 29,400 acres (11,900 hectares)—out of the total 49,000 acres (19,900 hectares) of the plains of Settu and Kawachi—were flooded, the raging stream further rushing through and submerging the whole city of Osaka. In the flood of 1896, the embankment broke down, happily for Osaka, on the right bank, which circumstance saved the city from inundation. The damages to cultivated fields, however, seem to have been as great as in 1885.

Insufficient drainage occurs when the flood water is not carried off quickly, and its injuries are generally but indirect evils of the flood. At low water stage, the water to be drained in the plain of Yamasiro finds its way into the Uji, the Katura, or the Kizu Rivers, or into the confluence of these streams; and that of the plains of Settu and Kawachi runs into the River Ai, a tributary of the Kanzaki, on the right bank below Goriô;

while that below Hirakata, on the left bank, finds its way into the Yodo immediately north of Osaka Castle. When, therefore, the main stream rises, the flow of this water is arrested and consequently it flows over the adjacent cultivated land, often to a depth of several feet. The effect thereof, indeed, is not so disastrous as that of a real flood, inasmuch as it does not sweep away houses or kill men and beasts, but for cultivated fields it is quite as bad as a flood. The area damaged by insufficient drainage is 7350 acres (2980 hectares) in Yamasiro and 36,750 acres (14,890 hectares) in the plains of Settu and Kawachi, and if we add to it the damaged area around Lake Biwa, it amounts to 61,250 acres (24,800 hectares) in all. This alone will be enough to show that the damages due to poor drainage can by no means be overlooked.

The Design of Works.

The improvement works of the River Yodo are, to all intents and purposes, defence works against flood. They are designed to prevent or mitigate damages inflicted by floods upon the districts around Lake Biwa and upon the plains of Yamasiro, Settu, and Kawachi, and also to improve the drainage of water in the above-mentioned plains. The extent of the work was to be all the way from the lake to the sea. The design was proposed by the writer, then head of the Fifth Engineering Inspection Bureau (Osaka), and was approved by the Council of Experts specially appointed by the Government to examine it.

In order to determine the requisite section of a river it is essential to know its maximum discharge, but when the design was drawn up, little was known about the maximum discharges of the rivers with which I had to deal. Therefore, putting together the results of observations made in ordinary floods, taking into consideration the coefficients of discharges, and applying them to the highest flood-level on record, I worked out the maximum discharges as follows:

	cu. ft. per sec.	cu. m. per sec.
Seta (being the upper course of the Uji)	25,000	705
Uji	30,000	850
Katura	70,000	1,980
Kizu	130,000	3,680

The maximum discharge of the Yodo after the confluence of the Uji, the Katura, and the Kizu is theoretically the sum of the maximum discharges of the three streams, namely 230,000 cubic feet (6510 cu. m.). As it is not possible, however, for all the three streams to send their maximum discharges at the same time, a deduction of 30,000 cubic feet (850 cu. m.) was made and 200,000 cubic feet (5660 cu. m.) was taken as the maximum discharge of the Yodo. Our object was to give the river a section large enough to carry down this volume of water.

The drainage area of the Seta is the entire province of Omi, and is equivalent to 46 per cent of the whole drainage area of the River Yodo; that of the Uji, which is the lower course of the Seta, is naturally a little more and is equivalent to 53 per cent of it. Those of the Kizu and the Katura are respectively 20 and 15 per cent. The remaining 15 per cent is the drainage area of the river after the confluence of the three streams and has little to do with the maximum discharge, since the water in the lower course flows down before the maximum discharge of the whole river is attained.

The reason why the Uji, which has more than half of the drainage area of the whole river, has only 15 per cent of the total discharge must be found in the fact that Lake Biwa acts as a great regulator. As this function of the lake has much to do with, and is indeed the basis of, the design of our work, a word on the regulating action of the lake will not be unnecessary.

Lake Biwa has an area of 279 square miles (723 sq. km.), i. e., 7,810,000,000 square feet (725,550,000 sq. m.), and its periphery measures 146.4 miles (235.5 km.). The volume of water from the surface to the depth of 1/10 foot (3.05 cm.) is estimated at 781 million cubic feet (22,100,000 cu. m.). To discharge this volume in a day, the water must flow at the rate of 9000 cubic feet (255 cu. m.) a second; or discharging continuously 25,000 cubic feet (705 cu. m.) (the maximum discharge of the Seta before improvement) it would take 8 hours 40 minutes 40 seconds for the above volume. This will give some idea of the vastness of the lake as a reservoir. But to see in a more concrete way the regulating action of the lake,

it is necessary to ascertain the relations between the volume of the water that flows into and out of it.

The volume of the water pouring into Lake Biwa is the sum total of the discharge of the rivers that flow into it and the amount of the rain which falls on its surface. But as it was no easy task to ascertain the discharge of all the rivers, an indirect method was adopted for the purpose. Now, in the flood of 1885, the greatest rise recorded took place in the 24 hours between the mornings of the 1st and the 2nd of July, when the water rose 1 ft. 4.8 ins. (0.43 m.). During these hours water increased at the rate of 126,000 cubic feet (3560 cu. m.) per second. This volume added to the 20,000 cubic feet (565 cu. m.) per second, which was the discharge of the Seta at that time, makes 146,000 cubic feet (3960 cu. m.) a figure which approximately represents the total influx, and the outflow shows that it is equivalent to only 14 per cent of the influx; from this one may see the wonderful regulating function performed by the lake.

We have hitherto seen the influence of the lake on the discharge of the Yodo at high water. Its influence on the discharge at low water is no less great. According to the results of observations, the minimum discharge of the Kizu is 800 cubic feet (22.6 cu. m.) per second, that of the Katura 500 cubic feet (14.2 cu. m.), while the discharge from the lake is rarely less than 5000 cubic feet (142 cu. m.) per second. This is why the main stream of the Yodo maintains its usual depth, occasioning no hindrance to navigation even in the dry season.

The projected improvement works were of three kinds: the works on the upper channel (called the Seta), those on the middle channel (near Yodo and Hirakata), and those on the lower channel (near Osaka). They are explained in due order below.

The works on the Seta comprised the dredging of the bed and the construction of a movable weir at Domagasima, an island in the river. As has been already stated, the injuries caused by the lake are due to the rising of the water-level, and any design for the prevention of the flood must aim at lowering this level. To attain this object, the only way is to increase

the discharge of the Seta, the only outlet of the lake, by dredging it. The object of the weir is to regulate the discharge of the Seta, both for the benefit of the lake and the lower course.

The flood of Lake Biwa is termed "ordinary" when the flood-level exceeds three feet (0.914 m.) above the normal level, and "extraordinary" when it exceeds six feet (1.83 m.) above the normal level. It was ascertained by investigation that the lowering of the water-level of the lake to the extent of three feet (0.914 m.) in no way interfered with navigation or irrigation on or around the lake. If, therefore, the lake-water was drained in winter when the season was dry and no harm could be done to the lower course until the normal water-level was lowered three feet below the former normal level of the lake, then an ordinary flood that came almost annually and most harassed the people could be wholly prevented, and even extraordinary floods could be so far mitigated as to change them into ordinary floods. All this could be done by the dredging of the Seta.

The Seta is rather a slow stream with a fall of 0.21 ft. per 1000 ft. for the distance of 2.5 miles (4.02 km.) from the "Karahashi", one of the "Eight Sights of Omi", and then it gradually assumes the appearance of a rapid, the fall increasing to 1.164 ft. per 1000 ft. for about 1¼ miles (2 km.), and thence it is a rushing torrent. The river bed near Domagasima was high, as if a great dam lay there, and it was clear that by dredging the shallow portion of the bed for a distance of 3.66 miles (5.9 km.) down from the "Karahashi", the discharge of the lake could be easily increased. The strata were in some parts rather hard, but on the whole they were soft and suitable for dredging.

Then the degree of dredging was considered. To proceed with the sole object of lowering the level by three feet (0.914 m.) would not have been a bad plan, but it was thought more profitable to increase the speed of draining and also to regulate the discharge by means of a weir. We, therefore, adopted the latter plan and so designed the weir that when it was open the discharge of the Seta might be doubled and the level of the lake might be lowered in half the time. For this purpose it was necessary to dredge the river bed for about 3½ miles (5.6

km.) above and below the weir and to give the river a width of 360 feet (109.7 m.), a depth of 12 feet (3.66 m.) below the normal level, i. e., 9 feet (2.74 m.) after improvement, and a slope of 1/3900.

The weir, when left open, must give the river a sufficient section for its maximum discharge, and must be adjustable at will so as to regulate the discharge. Masonry piers were to be built across the river, leaving thirty-two openings, each provided with a number of horizontal beams to regulate the water passing through it. Moreover, a step a foot high was to be made at the bottom of the weir, so that when it was full open there might be a fall necessary to let pass the required amount of water.

The bottom of the weir is on the same level as the bed of the river (270 ft. [82.3 m.] above datum), and the beams may be laid in, one over the other, up to the height of 19.5 ft. (5.95 m.) above the bottom. This height corresponds to 6.97 ft. (2.12 m.) by the water-gauge at Torii-gawa (the zero of which is 282.53 ft. [86.17 m.] above datum), or 7.22 ft. (2.2 m.) above the normal level by the same gauge after the completion of the improvement works.

Domagasima was chosen for the site of the weir because at this point the water is divided into two channels by a low island, giving the river a wide flood channel, and the works could be executed in the main channel by means of cofferdams.

The section of the Seta being enlarged by dredging, the water would fall lower than the intended level, if the weir were left open all the time, and it is necessary to regulate it by closing the weir. The artificial lowering of the water-level of the lake should be done in winter, for then the river has a small discharge and no damage would be done to the drainage, etc., of the riparian land along the lower course. At other times the discharge of the lake should be kept in the usual condition as far as possible, for the water-level stands high in the lower course. If in flood time there is any fear that the lower course may overflow, the lake water may be temporarily stopped by closing the weir. In this case, the check of the maximum discharge of the Seta (25,000 cubic feet [705 cu. m.]) would lower the water-level of the lower course by 2 ft. (0.61 m.) and would greatly lessen the danger of flood. The closing of the Seta

would cause the lake level to rise at the rate of ¼ foot (0.076 m.) a day, and since it takes three days in the lower course for a great flood to be out of danger by falling four or five feet (1.2-1.5 m.) from its crest as shown by the flood of 1885, impounding the lake water for three days would only raise its level ¾ ft. (0.228 m.) at most. Besides, the lake level could be previously lowered by the improvement works, and once the weir was open, the water would flow down at double the former speed. Thus the temporary stoppage of the Seta would cause no serious inconvenience to the country around the lake, while its benefit for the lower course would be inestimable. All this might be done by means of the weir. But the full advantage of a weir can only be obtained by long experience after its construction, and the above is merely a brief explanation of its working.

The object of the works in the neighbourhood of Yodo was to turn the stream of the Uji to the left of Yodo and to make it join the Kizu in a nearly straight line at Yawata, and also to extend the narrow outlet of the Katura and bring the confluence about 2½ miles (4.02 km.) lower down, to the vicinity of Yamazaki. The marsh of Ôike had hitherto been connected with the Uji, but we decided to cut it off by the left embankment of the Uji now to be constructed, and allow its stagnant water to escape through a new channel to be cut along the embankment. Moreover, a sluice was to be constructed at the end of the canal, in order to prevent the water of the main stream from flowing up in flood time.

The whole district at the confluence of the Uji, the Katura and the Kizu, is a great marshy tract of land with Ôike as its centre. Ôike served as a regulating reservoir for the Yodo in flood time, but its low-water area is only 2450 acres (994 hectares) though its flood area is about three times as much, and its regulating capacity is too insignificant for such a large river as the Yodo, while damages due to inflowing flood are not of negligible magnitude. Consequently, we decided to leave the work of a reservoir solely to Lake Biwa and to save the low-lying land around Ôike from inundations by disconnecting it from the main stream. The diversion of the Uji involved the separation of the Katura from the main stream;

at the same time the confluence of the latter was lowered a few miles, and as we have seen, the new embankment on the left bank of the Uji served to shut off Ôike.

These improvement works were expected to have the following effects: The Uji being thus given a channel of its own, all the flat area around Yodo would no longer be subject to annual inundation; Ôike being disconnected from the river and having its own channel of flow, its water-level would be lowered and consequently the neighbouring land freed from floods. While the discharge of the Katura at low water is only 500 cubic feet (14.2 cu. m.) per second, that of the Uji is at least ten times as much, and the latter tended to raise the level of the former; by separating the two channels and taking the former's confluence about 2½ miles (4 km.) down stream, its low-water level would have been considerably lowered and, consequently, the drainage of the low-lying land at and about Yodo and Yoko-oji would be considerably improved. Moreover, the widening of the confluence of the Katura would increase its flowing efficiency and prevent the breach of its embankments, adjoining above, which used to break very often. Of all these effects we had no doubt.

The new course of the Uji was designed to be 900 feet (274.3 m.) in breadth, and in the middle portion a low-water channel 300 feet (91.4 m.) broad was to be excavated. The Katura also was to be 900 feet (274.3 m.) in breadth, though where it was broader it might keep the original breadth, and a low-water channel 180 feet (54.9 m.) wide was to be cut in the middle. Since in the case of both rivers the water-level at the confluence was apt to be raised by the flowing up of the Kizu, the height of the banks was designed to be 20 feet (6.1 m.) above the low-water level of the Kizu, with a breadth of 18 feet (5.5 m.) at the top and side slopes of 2:1. The embankments of the Uji were to be faced with stone-pitching halfway up on the river side.

Near Hirakata the breadth of the main river was extremely narrow and often impeded the discharge of the flood water, the result being the breaching of its banks. In the flood of 1885, 30,625 acres (12,410 hectares) of the plains of Settu and Kawachi were devastated and rendered barren. We, therefore,

projected to widen the breadth of the river and afford it a sufficient section for the free discharge of the flood-water.

Where widening was not necessary, the old banks were to be enlarged so as to give them a surface 18 feet (5.5 m.) wide on the top, side slopes of 2:1 and a height of 3 feet (0.914 m.), at least, above the flood level. This was the standard of bank building we decided upon.

The upper stream of the Katura and the Kizu had no place in our design. The course of the Katura through the flat country below Arashiyama is in the wildest state, the breadth has nothing like uniformity, and the bed is almost entirely silted up with sand and gravel, while the low-water channel changes its position at every flood. This is usually the case with rivers in Japan when they emerge from mountainous districts into level districts. The reason is that when the water that has been rushing down steep ravines is hurled on flat land it suddenly loses its speed and deposits the detritus it has been carrying, leaving the river to find its course where it will. With a river of this sort, therefore, it would be useless to attempt to cut a new course or otherwise improve it, as it would relapse into its old condition as soon as the first flood took place. The wisest, though not the quickest, way is to effect a reform on the source of the river and prevent the detritus from being carried down. The Kizu is less torrential than the Katura, but it also carries down a great deal of sand whenever there is a flood, owing to the neglected state of the source of the stream, and the bed below the town of Kizu is formed by fine sand. The natural features of the Kizu are, on the whole, good, and as in the case of the Katura, the improvement of the source should precede the widening of the breadth, the enlargement of embankments, and other works on the river itself. This is the reason why the two streams were not included in our design.

The River Yodo below Sata divides itself into three branches: the Kanzaki, the Nakatu, and the main stream; yet the total of their cross-sections is very small. While it is 1800 ft. (548.6 m.) wide above Sata, it becomes, after the bifurcation of the Kanzaki (whose breadth is 330 ft. [100.6 m.]), only 780 to 960 ft. (237.7-292.6 m.) wide and further diminishes to 480 to 660 ft. (146.3-201.2 m.) after the bifurcation of the Na-

katu, whose breadth is 420 ft. (128 m.). It is too clear that with such cross-sections the Yodo cannot possibly carry down the flood discharge, and we took it upon ourselves to reform this state of things. We decided, therefore, to widen the old river between Sata and Moriguchi and to cut a new course in the direction of Daido near Moriguchi, where it is too curved, turning the old right bank into the left bank of the new course; at Akagawa the new course was to return to the old; at Kema the left bank of the old river was to be removed further back; then taking in part of the Nakatu, to lead the course in a fairly straight line to Denbô and thence to the sea. The total length of this section is 9.8 miles (15.77 km.). The width of the new course was to be 1800 ft. (548.6 m.) on the upstream end of this section and 2700 ft. (823 m.) on the lower stream, while it was to have a uniform low-water channel 480 ft. (146.3 m.) wide in the middle. The slope of the water-level was to be 1 in 4000 on the lower course (3.3 miles [5.31 km.]). The embankments were to be constructed according to the prescribed standard, with the exception of the portion protecting Osaka, which was to be 24 ft. (7.31 m.) wide on the top in order that it might be specially strong.

The River Kanzaki was to be dammed at the bifurcation in order to prevent the flood water from running in, and a sluice with a discharging capacity of 1000 cubic ft. (28.3 cu. m.) was to be built for purposes of irrigation. This arrangement was expected to drain off the plain on the right side of the Yodo below Goryô, to increase the discharging efficiency of the Ai, a tributary of the Kanzaki, and consequently make dry all the adjacent low-lying land.

At the bifurcation of the new Yodo River, we designed the construction of a movable weir and a lock, named Kema Weir and Lock, whereby only the low-water discharge (4000 cubic ft. [113.3 cu. m.] per sec.) might be passed and Osaka might be entirely freed from flood, while the facilities of water communication between Osaka and the upper stream of the River Yodo might be kept up by means of the lock. This project, moreover, would prevent the silting up of the Aji, the seaward entrance of Osaka, and at the same time increase the discharging efficiency of its tributary, the Neya, the great

drain of the 49,000 acres (19,830 hectares) of Settu and Kawachi, as the Ai in the case of the Kanzaki. This would indeed be killing more than two birds with one stone.

The lock was designed to be made of brick, with a chamber 270 ft. (82.3 m.) long (effective length) and 36 ft. (11 m.) wide and provided with iron gates manipulated by man power. The weir was to be constructed by the side of the lock. Its structure was to be the same as that at Seta, except that this was of a smaller scale than the other. It was to have ten openings, each 12 ft. (3.66 m.) wide, and to be regulated with horizontal beams. It was also planned to make a canal about 2.5 miles (4 km.) long between the lock and the confluence of the Nakatu along the new left bank, for transportation pending the execution of the improvement works, for irrigation, and for communication by water, within the neighbourhood, inasmuch as we felt sure that the adjoining land would develop into an important industrial suburb of Osaka in the future.

Further, it was designed to construct a lock at Denbô for facilitating the water traffic between the old course of the Nakatu and the new Yodo; another in the River Rokkenya to connect the old Nakatu and the Aji; an overflow dam in the Shôrenji to maintain, with the help of the two locks above referred to, the old level of fresh water in the section cut off by the new bank of the Nakatu, for the benefit of manufacturers,* and finally a small lock at the point where the new bank was to cross the Nisijima, for facilitating navigation between Amagasaki and Osaka.

The Execution of the Works.

These Improvement Works came under the control of the Fifth Engineering Inspection Bureau (Osaka), of the Home Department, and in the capacity of Director and Engineer of the said Bureau, we created, for this purpose, a special office, and, as regards field work, divided the whole river works into the three Engineering Sections mentioned below, establishing a separate station for each section. Each station had several substations attached to it, and thus the works were executed under direct official management.

* The estimates for the lock of the Rokkenya and the overflow dam in the Shorenji as supplementary works were sanctioned later.

1st Section	From the mouth of the river to Sata.
2nd Section	From Sata to Fusimi.
3rd Section	From the outlet of the lake to Sekinotu.

When these works were first started, the methods of execution usually adopted in this country were not in an advanced state, the use of machinery being limited within narrow bounds. But in public works of this magnitude, it was clearly impossible to follow the old methods and rely solely on manual labour. An extensive use of machinery was indispensable. Under these circumstances, the methods of execution were first decided upon, and such special kinds of machinery as could not be purchased in Japan were ordered from abroad, for which purpose we dispatched engineers to foreign countries. The kinds of machinery used for earthwork are chiefly as follows:

Excavators	3
Locomotives	6
Wagons	660
Rails for wagons	7228 metres (7900 yds.)
Dredgers	6
Unloading machines	3
Steam-tugs	6
Decauville light wagons	760
Rails for above	5847 metres (6394 yds.)

The cost of machinery, including the above and other tools and machines, together with the cost of repairs, reached a total of $865,000. These repairs were done in our own workshops.

One of the most difficult questions in connection with river improvement works is the appropriation of land. An improper method of doing this will seriously hamper the progress of the work, to say nothing of the large funds which are necessary for the purpose. According to the usual method, the authorities appropriate at one time only so much land as can be worked on in one year. But the consequence of this method is that the land to be appropriated the next year rises in value, as will easily be seen from the fact that these works themselves are primarily intended for the improvement of the riparian districts. Hence funds will become deficient, and a deficit in one year will cause inconvenience to the work of the same year, and this, again, will render satisfactory appropriation impossible in the following year. In view of these drawbacks, it was decided after careful consideration upon buying at once all the

necessary land before we set about the work. This new departure required, of course, a large amount of expenditure for the first year, but we were amply compensated by the speedy progress of the work, free from all inconvenience incident to the old method of appropriation.

The area of land appropriated for these works reached 2809 acres (1138 hectares). Many houses had to be removed. So several temporary appropriation offices were established in different places, and the officials of the Bureau attended to the matters pertaining to appropriation. In order to attain satisfactory results, there were included among the appraisers some of the private individuals who were well acquainted with the conditions of the localities, having at the same time good experience and enjoying the confidence of the local people. Thanks to this arrangement between the officials and the people the various disputes which too often arise in these matters and hinder the progress of the work were avoided. The following were the expenses required for appropriation:

Purchase of land	$1,453,568.617
Removal of houses, etc.	381,724.652

The Improvement Works consisted chiefly of earthwork, except such special works as the construction of weirs, locks and sluices, and some amount of rock excavation. The earthwork may be classed under three heads, namely, (a) banking, (b) excavation, (c) dredging. Under (a) come the construction of new banks, the enlargement of old banks, and the construction of dikes for closing the old river. Under (b) come the excavation of the low-water channel and the removal of high ground in the flood channel. And under (c) comes the dredging on the old river utilized for the new channel. Each of these works had to be subdivided into smaller portions, according to the physical features of the localities for the convenience of execution.

For making embankments, the excavated and dredged materials were used except under unavoidable circumstances. In dredging and excavating operations, the materials were used, as stated above, for making banks, and the balance, if any, was used either for raising low ground or filling in old river beds, in order to reduce the cost as much as possible, and only in exceptional cases were materials taken down-stream and

dumped into the sea. Thus excavation and dredging on one hand and bank construction on the other being closely related to each other, a brief explanation might be added about the classified figures given later on. The figures for dredging and excavation cover all expenses up to the furnishing of the material to sites where bank construction was going on, while those for banking include only the expenses required by the actual process of construction. But, when the materials had to be brought from other quarters, the expenses for bank making include also the cost of the excavation and transportation of these materials.

Except in the Seta River Section, that is, from Fusimi down, the improved river crosses the old river or is hemmed in between portions of its winding course. Accordingly, the works inside the old banks—namely, the excavation of the low-water channel, the removal of high ground in the flood channel, and the construction of the banks on both sides—had first to be taken in hand; then the old banks had to be cut away and the new river opened; and finally, the old river had to be closed. Such works as dredging on the old river or building locks and sluices had to be done all in due time.

Excavation was made by means of (a) excavators, (b) Decauville light wagons, and (c) human labour. The present Improvement Works were the first in which excavators were employed in this country, and at first considerable difficulty was experienced in operating them, but before long they were being worked at their highest efficiency. The excavators purchased were made by the H. Brulles Cie. and were of the bucket pattern moving on three rails, with an excavating capacity of 1600 cubic yards (1220 cu. m.) per day (10 hours) to a depth of 9 ft. (2.74 m.) below the ground surface. The excavated materials in the bucket are carried up along the ladder to the top of the machine, where they are emptied on to the shoot and are then loaded into the wagons at the rear of the machine. The ladder is so constructed that it can be raised or lowered by hand as the work proceeds. The wagon has a wooden receiver which has a capacity of 4 cubic yards (3.05 cu. m.), the receiver being inclined when the contents are to be emptied. The locomotive for hauling wagons weighed twenty tons and had a driving power of 180 tons (locomotive

itself excepted) on a track with a grade of 1 in 200. Thirty-pound rails were used for the transportation lines.

The excavators were used only in the First Engineering Section, and for each excavator there were 100 wagons and 1 locomotive. These wagons, with a reservation of a certain number, were divided into three groups, each group making a train. When one of these trains was loading at the back of the machine, another was waiting in the siding ready for loading, and the third was actually engaged in emptying, while the locomotive hauled them all by turn. The distance hauled was from 2000 to 4000 yards (1830-3660 m.).

The progress of work depends, of course, upon the harmonious working of the three factors above mentioned, in other words, hauling and emptying must keep pace with excavation. In the present works, the excavators were operated to their highest capacity, the locomotives did their full work, and the number of labourers was so proportioned that the emptying might not lag behind the other operations. However, the removal of rails from one place to another had to be carried out while the above-named operations were going on; this caused more or less inconvenience. Yet I am glad to say that the progress, on the whole, was highly satisfactory.

Four sets of Decauville light wagons were used, each set consisting of 150 wagons, and the length of rails reached 900 yards (823 m.) (curves and switches included). These wagons were chiefly worked by hand. This method of transportation was resorted to in those parts of the First Engineering Section where excavators were not used, and also in most parts of the Second Engineering Sections.

Excavation by labourers consists in loosening and carrying by manual labour. The labourers put the loosened material in a mokko (a sort of straw net) or a zaru (a sort of bamboo stretcher) and carry it on their shoulders on land, often followed by transportation on the water in small boats. This is the most primitive of all methods, and was used in all parts of the First and Second Engineering Sections in which neither of the above methods was used.

Dredging in the river was chiefly done by means of dredgers, which were of two kinds. The dredgers of the first class were pontoons of the bucket-ladder pattern, each with a

dredging capacity of 1600 cubic yards (1220 cu. m.) per day (10 hours); those of the second class were also of the same pattern, but with a capacity of 800 cubic yards (610 cu. m.) per day. One of the dredgers of the first class did the work on the portion of old river utilized for the new river in the First Engineering Sections, namely, at the mouth of the new river. The dredged materials were discharged into iron scows, each with a capacity of 80 cubic yards (61 cu. m.), and these scows, towed by steam-tugs, transported the materials to Tsuneyoshi-shinden on the left side at the mouth of the river. The unloading machine here installed had the same capacity as the dredger and could unload 1600 cubic yards (1220 cu. m.) per day. It was a bucket-ladder machine and was operated on a platform resting upon pile work. This machine unloaded the dredged materials brought in scows, and then the wagons, hauled by locomotives, carried the materials to the places where bank building was going on, and also to the jetty construction at the mouth of the river, the rest being dumped into the sea behind the jetties. The dredging on this section was comparatively easy, as the bottom was of sand or alluvium: but in unloading the alluvium we had some difficulty, for it did not dry up readily.

This work of unloading was not confined to the disposal of the dredged material on the lower portions of the stream; our first intention was to carry all the waste material from the First Section—namely, that from the upper portions of the river—down to this unloading machine by way of the Nagara Canal, which is also part of these Improvement Works, and, after unloading, to dump it into the sea. But as the said material was largely used for raising adjoining low ground, the waste which was brought down and unloaded by this machine did not amount to much.

The remaining three dredgers of the first class were employed on the Third Engineering Section, i. e., from the outlet of the lake down to Sekinotu. This distance was three miles and a half (5.6 km.). On this section, we had to dredge the bottom to a width of 360 ft. (109.7 m.) and to a depth of 12 ft. (3.66 m.) below the former normal water-level (9 ft. [2.74 m.] below the new normal water-level). For the transportation of

dredged materials we used 10 iron hopper barges—5 side discharging and 5 bottom discharging. These scows, towed by two steam tugs, carried the materials to a safe distance in the lake (1 to 2½ nautical miles (1.85-3.8 km.) from the outlet of the lake) and dropped them into deep water. The distance hauled averaged 4.1 nautical miles (7.6 km.), the scows plying up stream against a fall of 1 in 5000 to 1 in 3000. On this Section, a gravel stratum mixed with clay formed the bottom, and as it was difficult to dredge, especially in portions where the stratum was hard, the buckets were sometimes armed with steel claws. The nature of the bed being such, the machines were badly damaged.

The dredgers of the second class were used on the Second Engineering Section for dredging the low-water channel of the New Uji River course and also for dredging the old river bed from Yamazaki to Sata. In the Uji River dredging work, the dredged materials were loaded in scows and supplied as material for building banks on either side of the river. The materials from the old river, i. e., the section between Yamazaki and Sata, were transported down to Mayejima on the middle portion of the river, and, after being unloaded by the machine installed there, were utilized as material for reclaiming the neighbouring marshes.

The foregoing remarks are all concerning earthwork; the Dainichi Hill Excavation Work on the Seta River Section belongs to rock excavation. The object of this work was to take off that portion of the foot of Dainichi Hill which obstructs the flow of the improved river. Of the rock to be excavated, that above water amounted to 88,000 cubic yards (67,400 cu. m.) and that under water to 40,000 cubic yards (30,600 cu. m.). The rock was drilled before blasting, and the blasted rock was handled by the dredgers at work on the Seta River Section. The greater part of this rock was utilized for bank protection.

The Seta Weir and Kema Lock and Weir are the two important special works. The former has been constructed across the main stream at Domagasima. First it was ascertained by borings that a gravel stratum overlaid a stratum of hard clay. Hence we decided to lay a concrete foundation and enclose it with sheet-piling. In accordance with this plan, concrete was

deposited right across the stream, with a width of 88.5 ft. (27 m.), and sheet piles were driven around it. On this foundation were built piers of brick and stone. These piers have each the following dimensions:

Breadth	6 ft.	(1.83 m.)
Bottom length	24 ft.	(7.32 m.)
Top length	15 ft.	(4.57 m.)
Height	19.5 ft.	(5.95 m.)

Between the piers, openings (each 12 ft. [3.66 m.] wide) were provided for the passage of water, and each of the piers has vertical grooves made on the two sides facing the openings. These vertical grooves hold in position the horizontal timber beams, each 9 inches (22.86 cm.) wide, which are dropped into the opening to regulate the flow. The openings are 32 in number, their total width reaching 384 ft. (117 m.); the piers number 31, with a total width of 186 ft. (56.7 m.)—these two items making a total width of 570 ft. (173.7 m.). The upstream end of the abutment was bent landwards while the downstream end was extended 60 ft. (18.3 m.) to form bank protection. On top of the piers was built a bridge on which rails were laid for the easy conveyance of the beams, which can be raised or lowered by means of winches. The concrete foundation is 6 ft. (1.83 m.) thick under the piers and stone pitching between them, and 4 ft. (1.22 m.) thick in the apron below. For greater security, the river bed in front of the piers was covered with stone pitching 30 ft. (9.14 m.) wide and 1 ft. (0.305 m.) thick; besides, rip-rap was deposited below the apron for preventing the abrasion of the bottom.

The above work was executed in two sections; first, commencing at the left hand side, the stream was closed for a distance covering one half of the 32 piers, with a strong coffer-dam, which consisted of two rows of sheet-piles with clay filling between them. When this section was finished and the water allowed to flow through, the second section was taken up and executed in the same way. During the work nothing interfered with the progress of the operation.

The site of the Kema Weir and Lock is at the point where the old Yodo River branches off from the new Yodo River. This weir has the same structure as the Seta Weir, with timber

beams to regulate the flowing water. The water passages here are also each 12 ft. (3.66 m.) wide, and ten in number, while the weir is 23 ft. (7.01 m.) high. The nature of the bottom in this place required a special kind of work, for, upon boring, it was found that fine sand was underlaid with an alluvium stratum. As it was impossible to work by means of a coffer-dam, it was decided to lay the foundation for this work by sinking rectangular brick wells and filling the inside of, and the space between, them with concrete. In accordance with this plan, wells were sunk in one row across the stream instead of making a coffer-dam. And for the base of each pier, two additional wells were sunk close to the one already settled.

In laying the lock foundation, the same method was followed by sinking rectangular wells to the bottom of the upper and lower ends of the lock, as well as of the side walls. On this foundation were built brick walls; all corners as well as the hollow quoins and the mitre sills were made of stone. The lock floor was first constructed of concrete laid under water and, after drawing off the water, further concrete works were executed by ramming. The lock chamber has an effective length of 270 ft. (82.3 m.) and a width of 36 ft. (10.97 m.), and the lock is furnished with a pair of gates facing upstream only. There is no fall in the lock floor, and the water inside the lock is 7 ft. (2.14 m.) deep at low water, while in a flood the water in front of the gate is 13 ft. (3.96 m.) higher than at low water. The opening and closing of the gates is done by hand by means of cogged bars worked with gear-wheels on the lock walls. The filling and emptying of the chamber are regulated by the action of iron cylinder valves worked by a screw bar, the water passing through the culvert opening in the gate recesses.

For sinking the wells, both in the case of the weir and the lock, sand pumps and grab-dredgers were employed, dredging out the sand from inside of the wells to accelerate sinking. Owing probably to the uniformity of the soil, the wells went down without inclining or tilting.

We shall omit other minor works and give below a table of the whole Improvement Works classified according to the kinds of work and indicating the amount of each work done, together with the costs.

Table Showing Quantities and Cost of the Yodo River Improvement Works on Their Completion.

Kind of Work	Subdivision of Work	Length in Yards*	Amount of Earth in Cubic Yards†	Cost in Dollars ($)	Remarks
Excavation	Excavation of Low Water Channel		4,081,789.12	218,290.768	A little portion was done by Dredgers.
	Lowering Ground Level (in Flood Channel.)		3,573,318.72	160,581.753	
	Removal of Old Banks		2,446,532.32	98,275.395	
Total			10,101,640.16	477,147.916	
Dredging	Dredging on Old River		3,978,547.60	198,643.212	Whole work done by Dredgers.
Total			3,978,547.60	198,643.212	
Banking	(a) Construction of New Banks (b) Dikes for Closure	47,138.0 7,120.0	7,753,439.28	336,875.966	Including Cost of Bank and Bed Protection, etc., accessory to Banks.
	Enlargement of Old Banks	48,290.0	2,254,690.48	105,206.910	
	Jetties at New River Mouth	1,160.0	155,384.00	72,854.999	
Total			10,163,513.76	514,937.875	

* 1 yd. = 0.914 m.
† 1 cu. yd. = 0.765 cu. m.

Nagara Canal	Excavation	6,546.0	230,487.04	48,699.144	Bottom Width 36 ft.; Depth 5 ft.; with Sluice at Intake; Wooden Lock at Lower End.
Ôike Drainage Canal		4,180.0	170,320.24	34,983.420	Bottom Width 48 ft.; Depth 5 ft.; with Sluice at Lower End.
Dainichi Hill Rock Cutting			(Rock) 129,267.20	44,537.666	
Seta Weir				126,703.422	
Kema Weir				129,297.222	
Kema Lock				69,862.852	
Rokkenya Lock				59,222.901	
Denbo Lock				13,855.384	
Nishijima Lock				9,939.467	
Kanzaki River Sluice				12,780.057	
Yawata Sluice				7,307.179	
Overflow-dam on the Shorenji River				6,878.463	
Bank Protection				51,306.990	Chiefly Seta Bank Protection.
Miscellaneous				55,750.086	
Grand Total..........				1,861,853.256	

If we confine ourselves to the earthwork given in the foregoing table, and take only the material loosened and transported—i. e., material removed—and classify it only according to the definite methods of execution employed, then the costs per cubic yard of earth are as shown in the following table.

Method of Execution	Amount of Earth in Cubic Yards	Cost per cu. yd. For working	For repair	Total
Work by Excavators*	3,423,370.48	0.036	0.014	0.050
Work by Dredgers and Unloading Machines†	1,330,304.64	0.065	0.027	0.092
Work by 1st Class Dredgers‡	2,248,417.36	0.036	0.015	0.051
Work by 2nd Class Dredgers§	1,096,825.52	0.064	0.008	0.072
Work by Decauville Light Wagons	3,378,790.00	0.051	0.004	0.055
Work by Common Labourers	6,305,702.24	0.055	0.003	0.058
Total or average	17,783,410.24	0.050	0.008	0.058

The costs of materials used for the construction of the Seta Weir and Kema Weir and Lock are as follows:

	Seta Weir Per cu. yd.	Per cu. m.	Kema Lock & Weir Per cu. yd.	Per cu. m.
Cost of Concrete Work	$ 2.165	($ 2.83)	$ 2.718	($ 3.552)
Cost of Brick Work	4.522	(5.910)	6.423	(8.395)
Cost of Masonry	13.229	(17.290)	15.209	(19.878)

The prices of materials and labour are the basis of the costs given in the foregoing tables. These are rising every year in this country. For the sake of reference we shall give the average wages and payments per day during these Improvement Works:

* Executed in 1st Engineering Section.

† Executed on Lower Reach of 1st Engineering Section, and also on the Middle Reach of 2nd Engineering Section.

‡ Executed on the Seta River of 3rd Engineering Section.

§ Executed in the 2nd Engineering Section.

Labourer	$0.30	per day
Carpenter	0.40	" "
Mason	0.60	" "
Captain (of dredgers and steamboats)	1.00	" "
Engineer "	0.75	" "
Engine driver	0.40	" "

Total Cost of the Works.

The original estimates authorized for these Improvement Works were $4,547,000, of which $982,500 was borne by Osaka-fu, $184,500 by Kyoto-fu, $189,500 by Shigaken and the remaining $3,195,000 by the Treasury. These were the estimates at the commencement of the works, but the River Law was subsequently promulgated, and according to its provisions we had to subsidize local corporations from the above estimates for the accessory works, besides executing some supplementary works. Consequently $500,000 was authorized in addition to the above sum, of which $125,000 was borne by Osaka-fu and the remaining $375,000 by the Treasury, the total estimates amounting to $5,047,000. The settled account for these works reached $5,031,106,516, the balance being $15,893,484. The details of expenditure are as follows:

Cost of Construction	$1,861,853.256
Expenses for Purchase of Land and Removal of Houses	1,835,293.269
Cost of Machineries, Boats and their Repairs	865,254.142
Miscellaneous Expenses*	251,413.307
Subsidy for Accessory Works	217,292.542
Total	$5,031,106.516

* For surveying, water-gauges, buildings, telephones, lower employees, etc.

Paper No. 34

IRRIGATION ENTERPRISE IN THE UNITED STATES.

INTRODUCTORY PAPER.

Outlining the Various Ways in Which Irrigation Enterprises Have Been Handled.

By

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INTRODUCTION.

The almost universal desire in countries which are but sparsely settled and in which natural resources are still latent to develop these resources faster than similar resources are being developed elsewhere has prompted the people the world over to encourage, for a time at least, the development of these resources by private enterprise. Private ownership of the field upon which cattle graze, on which wheat, corn and fruit are grown, and upon which the family lives has been the natural result of this desire, which was fostered by those in power just as soon as government had been advanced to the point of effectively protecting life, liberty and property. By common consent—though as many believe, not wisely—perpetual private ownership of land is a condition almost universally established, regardless of the fact that land, like the air and the water of the globe, should belong to all in common, with only temporary rights to possess and to use granted to those who, from preference or special adaptability, will make better use thereof than could be made if equal distribution to all were attempted.

The feverish desire to rush the development of natural resources, particularly in the frontier countries, has led to the offering of material inducements to enter upon such develop-

ment, often in advance of actual need, and these inducements, in many cases, are out of all proportion to the advantage that results from early development. Where the government is strong and where wise counsel has prevailed, the precaution has been taken to let ownership in mines, in navigation canals, harbors, railways and in public utilities generally, at least in so far as franchise rights are concerned, revert to the public in the course of time. Where, as in the case of our own country, the science of government is still new and largely experimental, the influence of the land-grabber and of the exploiter of mineral, water and other resources has been too strong to be resisted and there is found here absolute and perpetual ownership in mineral deposits, in certain water rights and in franchises of various kinds, which, if such matters were to be newly programmed, would not now be granted without reversion in due time to public ownership.

Water as a necessity to human existence should be as free as air. The right therein to sustain life is common to all. But water is not like air, to be found everywhere and at all times. To make it available in the necessary amount and of proper quality at the places and for the purposes wanted, works have to be constructed, often of great magnitude and at great cost. To compensate those who make the investment in these works, when privately owned, or to meet the expense which the installation and maintenance thereof have put upon the Government, a charge has to be made for the delivery of the water, and this charge usually bears some relation to the amount of water delivered or, in other words, to the value of the service rendered.

Demands upon the financial resources of practically every government for police protection, sanitation, the maintenance of a postal service, for aid to commerce, and for ordinary public works are usually so great that funds can not always be made available for such purposes as the development of minerals or for the development and distribution of water power, or for the construction of irrigation works. The cost of these must generally be met in some other way than out of the public treasury, particularly, in view of the fact that their construction may confer special benefit upon only a part of the community. There

is no reason apparent, however, why, along with other utilities, such works as irrigation canals, swamp-land reclamations and flood-control projects should not, when conditions permit, be paid for out of the general treasury, provided, of course, that an adequate charge be made for the service and interest be paid by the property benefited in perpetuity or that the invested capital be returned to the treasury in the course of time.

The fact remains that this course is rarely feasible and that it can not be adopted on the frontier in sparsely populated regions where there has not yet been a sufficient time or opportunity for the accumulation of wealth.

Liberal concessions to the railroad builder, bringing rewards sometimes out of all proportion to the service rendered, have caused railroads to be extended into territory which without the railroad would have made slow progress but which with the railroads advanced by leaps and bounds.

A similar policy in the case of the irrigation canal would, no doubt, have hastened the construction of works for conserving and utilizing for irrigation the water of the stream which even at the present day, in this country, is utilized to only a small fraction of the ultimate possibility.

The first settlement by the white man was on the banks of the stream. Its water added value to the land, perhaps because the water was navigable, perhaps because it was a dependable supply for domestic use, perhaps because of the power in the current or in the fall of the stream, and perhaps because the stream diverted upon the land would increase the productiveness of the farm.

The first settler, at any rate, according to his means and according to his light, took advantage of the natural water resources of the region which he selected for his home. As a general proposition, the riparian land was preferred to that which had no frontage on a stream and, to some extent, the riparian doctrine, which recognizes the advantage of a frontage on a stream, has found acceptance in some of our Western States.

This doctrine, where it prevails, has given the riparian owner an advantage over the appropriator and has in some cases been a material factor in shaping the irrigation development. This would have been quite acceptable if in all cases the

riparian land were the best, all circumstances considered, for irrigation from the stream. But it frequently happens that this is not the fact, that more land could be irrigated and better results could be obtained if there were complete diversion of the flow from the stream, with application to land extending far away from the strip of land along the stream which, under any interpretation of the doctrine, could be regarded as riparian.

Lands everywhere could be had at little or no cost when the settlement of the public domain commenced. Good land, on which crops could be raised and on which orchards would flourish without irrigation, was naturally the first to be improved. Irrigation could not be had without expense. Irrigation was out of the question so long as fertile lands not requiring irrigation could be had at a low price.

As time went on, land values rose, the semi-arid lands with water, under intense cultivation, and with markets for their products, established new standards of productiveness and a strong impulse was given to investments in irrigation works.

The various States of the Union have been slow in defining the rights to use water. Only here and there, as in Wyoming, under the guidance of Mr. Elwood Mead,* in Colorado, in Oregon, Nevada and in a few other of the Western States, has suitable provision been made, first, for the acquirement of the right to use water and, second, for the protection of the owner of a water-right in the enjoyment thereof.

In the struggle for the individual right recourse was had to every basis that could be put forward to strengthen the litigant's claim, and too often the plausible riparian doctrine has won out. The rights which the same confers upon the riparian land have never yet been satisfactorily defined. It is not even possible to determine from the statutes or from the court decisions what the limit of the land is which is riparian, nor whether the riparian owner when he diverts water from the stream upon his back-land is not to be classed as an appropria-

* Mr. Elwood Mead, formerly State Engineer of Wyoming; later at the Head of Irrigation Investigations, U. S. Dept. of Agriculture; subsequently Chairman Board of Water Supply, Victoria, Australia; now Professor Rural Institutions, University of California.

tor. Nevertheless, the doctrine gives the owner on the lower sections of the stream a standing in court against all appropriators on the stream and on its branches above his holdings, not alone when it comes to making a diversion of a part of the ordinary flow but also when the storage of flood waters is involved.

In some cases, as, for example, on Kern River in California, this has been carried to such an extreme that even a modification of flow conditions, not necessarily involving any reduction in volume of discharge, has been used by the holders of rights further down on the stream as the basis for a demand for compensation. The power company, which returned all water used to the river from which taken, paid for the privilege, though perhaps only to avoid legal controversy.

This circumstance is cited merely to give some idea of the inadequacy of the water laws of some of the States. The courts must be resorted to in some of the States to define rights as between individual claimants, and the courts must be again appealed to when, by reason of less favorable position on the stream, the rights of one water taker are encroached upon by another who is more favorably located.

IRRIGATION ENTERPRISES.

Irrigation works in this country have been and are being constructed:

(a) By the owner or owners of the land to be irrigated

(b) By private owners, usually corporations, as public service properties, for profit

(c) Under the Desert Land Act, which permits a combination of land owners to join in the development of a common source of supply

(d) Under the Carey Act, which permits the development of a water supply for the irrigation of the public domain, after cession thereof to the State in which located, and which permits the sale of the land at such prices that the cost of the works, with adequate profit, is returned to the promoter of the enterprise

(e) Under the U. S. Reclamation Act, which permits the construction of irrigation works, at Government expense, for

the irrigation of land in the public domain as well as of land in private ownership, and requires a distribution of the cost to the land irrigated

(f) Under State irrigation district laws, which permit the formation of districts embracing lands capable of being irrigated from a common source of supply, and authorizes the issuance and sale of bonds

Combined Ownership of Lands and of the Irrigation System.

The early irrigation canals in the United States were built by the owners of the lands to be irrigated. Probably the first, barring possible small ditches on privately owned lands in the Colonies, were the canals constructed nearly 140 years ago for the irrigation of Mission lands in California. Small areas were involved and the works were not of large magnitude; nevertheless, they represented diversions of water to a greater or lesser distance from the streams for the irrigation of the canal owners' lands.

Generally, the works constructed by the land owner for the irrigation of his own land were, like the Mission canals, of small magnitude, but as time went on a number of owners here and there found it to be of mutual advantage to construct works of common benefit, with the result that larger enterprises became possible. This naturally led to the formation of mutual companies, interest in which is generally represented by ownership of stock, and such companies have been operating throughout the country with more or less success.

At the outset, their difficulties were chiefly those inherent to construction and maintenance of works. A little later, as the irrigated area grew and their neighbors, like themselves, were making larger demands upon the stream, the struggle for enough water became a serious matter, which was fought out in the field and in the courts and is in many of the States still far from final settlement.

The chief difficulty in the successful carrying out of irrigation enterprises by the owner or owners of the land to be irrigated lies in the fact that the cost of the works is usually so great that there is difficulty in financing such enterprises. Cooperation of a number of independent land owners is not always as harmonious as it should be, and the high order of in-

telligence necessary to carry the larger irrigation enterprises to a successful outcome is not always found among the owners of the areas subject to irrigation from a common source. To such circumstances as these may be ascribed the fact that mutual ownership of irrigation canals has not proved more popular and general than it is, although, by such co-operation the ideal of a combined ownership of land and water is brought about.

Many of the mutual concerns now in successful operation had their inception as commercial enterprises. The scheme of organization provided, in such cases, for a gradual transfer of ownership from the original canal builders, as the area irrigated was extended, to the land owners. This was accomplished in some cases by restricting ownership of stock to the owners of the land which is subject to irrigation by the enterprise, and in others, as in Colorado under the Anti-Royalty Act, by a transfer, after a certain degree of development of the canal system, to the water-users.

Commercial Enterprises.

There has been, as explained, all along the line in this country an inadequate definition of the right to use water for irrigation and an inadequate protection of ownership in such rights. This condition is fast being remedied. But it prevailed so long in many of the States that the canal owner, and particularly the canal owner who has made his investment in the canal property for profit, has frequently had a hard time of it. Not only has he often found it a great burden to establish and maintain his rights but, due to the low value of land, to the abundance of opportunity elsewhere, or to the inadequate market for the products of the irrigated farm, he has found the land owner slow to adopt methods of intense cultivation, and 10 to 30 years have frequently elapsed before the use of water became fairly general on the land commanded by the canal.

To illustrate. The Crocker-Huffman Canal on the south side of Merced River, California, is an enlargement of the Farmers Canal. As a cooperative enterprise, the original canal, some 22 feet in width, proved too burdensome to be carried by its original owners. The canal was sold, and enlarged by its new owners to a width of 80 feet with a water depth of 10 feet;

about $1,500,000 being reported to have been expended within a few years in making the enlargement and in providing for Merced a water-supply system from a reservoir fed by the canal. The lands commanded by the canal are well adapted for cultivation by irrigation, being smooth surfaced and fertile. But they were all privately owned, and the owners were not ready to change in a day from a primitive system of unprofitable dry farming to a system of farming requiring a large expenditure for the preparation of land and the subdivision and sale of large holdings. Water was, therefore, wanted only here and there on relatively small tracts which could not be served to advantage. The canal business, as a result, remained unprofitable for a period of more than 25 years.

When the Fresno Canal was constructed on the north bank of Kings River, for the irrigation of lands near Fresno, by M. J. Church—almost unaided—he soon found himself so heavily in debt that he had to let the property go to his creditors. Finding profitable management out of the question, these creditors turned the canal back to Mr. Church, and it was many years before the full value of this property, which has been the principal factor in developing the Fresno region, was realized.

A successful private enterprise, the example being again taken from California, is the "76 Canal", now the canal of Alta Irrigation District. This canal is located on the south side of Kings River. The promoters of this enterprise, realizing that they could not hope to make a profit on the sale of water, bought, before entering upon construction, all the land commanded by the proposed canal which could be had at less than $10.00 per acre. Most of this land, being located in a region with only about 10 inches of rain per year, was at that time being used only for pasturage. They acquired about 40,000 acres. As soon as the canal was constructed and water could be delivered, these lands were offered for sale at prices sufficiently advanced to more than cover the cost of canal construction. Three years after the completion of the canal, the canal company, as the result of an investment of $300,000 had property worth $800,000. When the Alta Irrigation District was formed the canal was sold at a good price to the district.

It seems self-evident in the case of the irrigation canal whose output of water must be used year after year within a certain limited area that the land and water should be in common ownership. It should not be possible for the canal owner to deprive any area dependent upon the canal from a proper quota of water, and to this extent the law in the Western States gives the land owner protection—neither should it be possible for the land owner to evade obligations which have once been assumed with reference to the use of water. This being the case, it seems desirable, whenever this is practicable, that the independent canal owner should be entirely eliminated.

Ordinarily the canal builder needs financial assistance when an irrigation canal of any magnitude is to be constructed. The practice has grown up, and is fairly well established, of demanding from the land owner a contribution, under the guise of a payment for a water-right, which is variously construed as an advance water-rate payment, or as a bonus. The so-called water-right is then the agreement which the consumer makes with the canal company. This is usually made subject to cancellation if any of the conditions contained therein are violated.

It would be much better, as is sometimes done, if instead of demanding a bonus from the land-owner the canal builder would sell to the land-owner stock in the enterprise proportional in amount to the area of land to be supplied with water, so that when more than one-half of the area to be irrigated has actually been brought under irrigation, the control of the canal will pass to the land owner.

Experience with the privately owned irrigation canal managed as a public utility has only in rare cases been satisfactory, and such private ownership is not to be encouraged.

Irrigation Enterprises Under the Desert Land Act.

To encourage the settlement of arid lands, the Desert Land Act was passed in 1877. Under this act entry could be made for 640 acres of land. In 1891, a supplemental act restricted the area that could be entered to 320 acres.

The entryman could secure water from any reliable source; he could combine with his neighbors or could secure a water-right from any established irrigation system. The practice

quickly grew up of entering into agreement with parties that were ready to finance an enterprise for the construction of the necessary irrigation system in return for a part of the land covered by the entry. While such contracts were illegal, they were made practically effective by stipulating for cash payments for the water, in default of which the entryman, without violating the law, could deed a part of the land entered to the water company.

Most of the land now under cultivation in the Imperial Valley, California, was entered as desert land. The main canal which supplies the water to this valley is still in private ownership. The water diverted within California from the Colorado River has to be carried, by reason of unfavorable topographic conditions, into Mexico and thence back into the United States. The head of the canal and the portion of the main canal in California is owned by the California Development Company. The section of the canal in Mexico is owned by a Mexican Canal Corporation. A project of this kind could not be carried out without the cooperation of a large number of entrymen. It need hardly be stated that very complicated and, in some measure, embarrassing situations resulted; but despite all obstacles wonderful results have been achieved. There is a strong movement now on foot to form an irrigation district embracing all irrigable lands in the Imperial Valley. By the formation of such a district and the purchase of the canal system, the private corporations now owning the canal would be eliminated.

The Carey Act.

While there have been some successes among the irrigation enterprises under the Desert Land Act, there have also been many failures. The companies which were organized to supply water to lands entered under this law could not control the entrymen. If agreements to take water were not voluntarily made they could not be forced. Some scheme had to be devised according to which the public land to be irrigated could be withdrawn from entry until the features of the irrigation project were determined upon and the cost thereof had been estimated. This led to the enactment of a law by Congress known, after its author, as the "Carey Act". Under this Act

the State in which desert lands are located could request a cession thereof to the extent of 1,000,000 acres and cause the same to be irrigated, reclaimed and occupied. Not more than 160 acres are to be disposed of, under this act, to any one person. Various defects in the original law have been remedied by subsequent enactment and the provisions of the original act which were limited for application to States were extended to the territories. The time within which the reclamation was to be completed was originally fixed at 10 years. It may now be extended by the Secretary of the Interior to 15 years.

Under the Carey Act there is some supervision by State authority over the various projects, but the desire to see results accomplished and the lack of an adequate organization supervision gave opportunity for launching many schemes which have proven of doubtful merit. It was found essential, finally, to exercise Federal control through project examinations before approving any segregation of land. This is now done in every case and goes a long way toward checking development where conditions are adverse and, particularly, where the water supply is inadequate.

The project under the Carey Act is financed by some company, which, under contract with the State or Territory, is allowed to sell water-rights to the purchaser of land at a price which is so fixed that it will return to the company the capital invested together with a reasonable profit. The State fixes also the price at which the land is to be sold. This price usually ranges from $.50 to $10 per acre.

The usual difficulty of raising money on the contracts made with the States is encountered in carrying out Carey Act projects. There has been disappointment here, as in most irrigation projects, in the rate at which land has been occupied and improved. No matter how alluring the situation may be the progress is slow. The speculator and the undesirable farmer can not be entirely eliminated, and even the thrifty farmer can not, in many cases, with the limited means at his command accomplish the results which had been hoped for. Such circumstances, coupled with instances of failure and practical abandonment of work for one cause or another, have discouraged investment in Carey Act securities. It will be dif-

ficult to re-establish confidence unless some way may be found of substituting the State for the intermediary project company. So far as known, no attempts have yet been made to do this.

The original supervision provided by the States which availed themselves of the privileges conferred by the Carey Act has not been effective, and never can be made so until the State itself assumes the responsibility for the success of each enterprise.

The United States Reclamation Act.

The U. S. Reclamation Act, which was passed by Congress in 1902, allows aid to be extended through the Secretary of the Interior to the settler upon arid lands. The benefits need not be restricted to lands in the public domain, but may extend to lands already privately owned, provided only, that large holdings be subdivided, so that home building will be encouraged. Under this Act an indirect appropriation was made and became available at once for use upon projects found to be feasible and economically advisable.

The Government takes complete charge of construction and expects the land owner to return to it the cost of the works. Interest is waived. In this way the direct contribution by the United States toward the cost of a project is not inconsiderable. Originally, ten years were fixed as the time within which repayment should be made, but this was found to be too short a period and has been extended to twenty years. An initial payment of 5% of the construction cost is required; and beginning five years after the first payment, there are required five annual payments, each of 5%, and, thereafter, ten annual payments, each of 7% of the construction cost.

The present value of all these payments is about 55%, if an interest rate of 5% per annum, which would be the least likely to be fixed on a district bond issue, be made the basis of calculation.

By waiving any interest charge, the Government is therefore practically extending aid to the extent of about 45% of the cost of the irrigation works now being constructed by the United States Reclamation Service.

In order to avoid the appearance of placing a direct appropriation in the hands of the Secretary of the Interior to be

expended on projects found by him to be worthy, the Reclamation Act provided that the receipts from the sales of public lands, except a small portion thereof which goes into a school fund, should become available automatically for the purpose. Funds accumulated rapidly and a large engineering staff was soon at work examining projects in all the Western States. In the absence of a Department of Public Works as a branch of the Government, it was necessary to build up a new engineering bureau. This was most conveniently done through the U. S. Geological Survey, whose hydrographic force, which had for some years been actively engaged upon the study of irrigation possibilities, was quickly transformed into an engineering bureau.

Projects were examined and reported upon, and water-users' associations were formed. The construction of the approved project was then pushed forward as rapidly as circumstances would permit. The Water-users' Association became necessary, as some lien upon privately owned land had to be given to the Government in order to induce it to extend the benefit of irrigation works to such privately owned lands. The land owners form the association. The land owner is expected to take as many shares of stock as he has acres. The estimated cost of the project fixes the face value of the capital stock. Each shareholder makes the payment upon the stock a lien upon his land and upon his capital stock. The Association enters into contracts with the Secretary of the Interior, which, through the Association, are made binding upon the land owner and his successors in interest. Entrymen are compelled to become stockholders. The Water-users' Association collects from its stockholders the funds needed to meet the installments due upon the irrigation system.

When after a time it became apparent that money was not becoming available as rapidly as needed for the advancement of many of the projects under construction by the Reclamation Service to the point where they could be made of use to the landowner, a direct appropriation of $20,000,000 was made to help out. This supplemented some $70,000,000 which had already become available under the indirect appropriation. No part of the $20,000,000 was to be used on new projects.

Thirty-two projects have been undertaken by the Recla-

mation Service. These are planned to irrigate ultimately about 3,000,000 acres of land. Water can now be supplied to nearly one-half of this area.

The requirement that the farm units should be small and the requirement that water should be delivered to each unit, in order that the individual land owner would be relieved of ditch work except upon his own property, has made the cost of the irrigation system apparently expensive, but not unreasonably so, particularly in view of the fact that wherever practicable the works are made as nearly permanent as possible. The old practice so prevalent in the West of using makeshift temporary structures to tide over the early years of small revenue was abandoned for the more burdensome, but otherwise better, policy of first-class construction. In some measure this increased first cost has contributed to the difficulties which have been encountered by the first settlers in making both ends meet; but will, without doubt, be found to be to the ultimate advantage of all concerned.

If any criticism may be ventured, it would apply mainly to the lack of thoroughness in studying the engineering and economic features of the several projects before they were authorized. Some haste in this matter, resulting in the undertaking of projects whose features were not fully worked out, has, no doubt, contributed to the adverse criticism which has to be met here and there.

The Reclamation Act was intended to be of special aid in making arid public lands available for settlement. Its provisions had to be extended to privately-owned lands because there is no longer any large body of the public domain which can be brought under irrigation without the inclusion of some privately owned land. Of this fact several localities, where almost all land is privately owned, have availed themselves, such as the region near Phoenix on the Salt River in Arizona, where the water supply has been made reliable by the construction of the Roosevelt (Tonto) Reservoir. As another such example with which the author is personally familiar, the Orland district in California may be cited where privately owned lands are very successfully irrigated from a system of works constructed by the Reclamation Service.

In the case of all works constructed by the Reclamation

Service, except storage reservoirs, ownership thereof passes to the Water-users' Association as soon as one-half of the cost thereof has been repaid to the Government. In this way, ownership of land is made to carry with it also ownership of the irrigation system.

The Irrigation District Law.

There should be no public service corporation between the owner of the land and the water which he needs for its irrigation. The owner of the land should also be the owner of the irrigation system upon which he is dependent for his water. This fundamental principle has led to the enactment, in a number of the Western States, of irrigation district laws. Under these laws the owners of land which is susceptible of irrigation with water from a common source may form a district. As practically all of the irrigation district laws have been patterned more or less closely after the California law, the remarks here made have been based on the law in California but may be applied with suitable allowances elsewhere.

Districts are formed by the supervisors of the county in which the land to be irrigated is located. There was originally no other requirement except a satisfactory showing by the interested parties that they had the necessary number of signatures and that the land was susceptible of irrigation from a common source. Volunteer testimony was often all that was offered. Now the State attempts some supervision over the formation of a district and bond issues are no longer possible without the approval of proceedings by certain State officials. When a district is formed it elects a board of directors—one from each of the five divisions into which it is divided—and these directors thereupon manage its affairs. Usually the area in a district is sparsely settled; there is but little material to choose from in selecting directors, and the complicated affairs of the district may have to be handled by persons who are illy prepared by training and experience to attend to such matters. However, progress is made by selecting an engineer, and works are soon designed and a cost estimate is submitted. Thereupon bonds are voted.

The law at first attempted to protect the district by requiring that the bonds should not be sold below a certain price.

This price was originally 90% of the face value, later it was par. Now the restriction has been removed. But by reason of early mistakes; by the creation of districts which could not be supplied with water or which were defective in other respects and could not meet their obligations, the irrigation district bonds were quickly discredited. They are not readily salable in the world's bond market, not even those which have the stamp of State approval through properly constituted authority. It will take time to undo the mischief that has already been done. But the situation was made worse than it would otherwise be by the districts themselves, which, in their anxiety to advance construction, sanctioned the evasion of the law and sold their bonds to dummies, through whom they were passed on to contractors. In this way even some of the districts which are now in successful operation had to pay from 25% to 75% more for their irrigation systems than the same would have cost if they could have been paid for on a cash basis. As a consequence of such procedure, the irrigation district bond is discredited. The bond of the successful district is not easily distinguishable from the bond of the unsuccessful district and despite every effort the market for district bonds does not improve.

The remedy for this condition seems obvious, though there may be some difficulty in applying the same. The irrigation district should have its limits defined by the State and the State should plan the necessary works. The property owners in the district should be given an opportunity to decide whether they wish to be taxed for the cost of the works planned by the State, and when they have assented thereto, the State should issue the necessary bonds. These bonds should not be predicated upon the success or failure of the irrigation project. They should be simply State Bonds. Thereupon, the State should proceed with the construction of the works, turning the same over when completed to the district and thereafter collecting from the property owners of the district such taxes as may be necessary to meet the interest on the bonds and a sinking fund, which should preferably be extended over a period of 35 to 45 years with no sinking fund increment in the first five years.

GOVERNMENT AID TO IRRIGATION.

Of all the measures which have been taken in the United States to encourage irrigation, the Reclamation Act is the only one which extends financial aid. There is nothing in the nature of a direct subsidy. The Government directs the expenditure of the money which it contributes, and it assumes full responsibility for the successful execution of the enterprises which it undertakes for the reclamation of arid lands or for the irrigation of the privately owned farms.

This is sound doctrine and should be the policy adopted by the individual States. The backing of an enterprise by a State will only then become of unquestioned value—when the State assumes responsibility. The tendency to secure this is apparent in the moves which are made with more or less success to secure State examination of projects, State approval of bond issues and a State guarantee of such issues.

Every State can afford to provide the machinery which would be necessary to examine, plan and construct irrigation works, and may well encourage worthy projects which are found to be economically advisable, because the relatively small burden that will result from the maintenance of an adequate department will come back many fold in the direct and indirect benefits resulting from the extension of irrigation.

Under such a policy, if properly and efficiently applied, the State will only loan its credit. When what it will gain is considered, it may well assume the risk of an occasional failure—admitted to be possible—if its officials should proceed with too great enthusiasm and without adequate preliminary studies.

The United States in extending aid in one form or another to the locality which needs irrigation is following, though with modifications of a more or less experimental character, the precedent established in older countries.

Thus, in France the Government will make loans on favorable terms to those who construct irrigation works and may waive taxes on increased land values; a part of the cost of the works may be advanced with the stipulation that the works themselves are taken in payment at the expiration of long time concessions; subsidies may be granted; securities may be guaranteed; works may be constructed by the State and turned

over to private syndicates for management, or the State itself may undertake the construction of the works.

In Italy, too, taxes may be waived and loans may be made to irrigation syndicates.

A similar policy prevails in Spain, where loans may be made to land owners for use in the construction of irrigation works, and also to syndicates for the construction of irrigation or drainage works. Taxes may be waived and subsidies may be granted in sums not exceeding 40% of the estimated cost of the works plus about $8.00 per acre of the area irrigated. The Government reserves the right to expend the money advanced on the storage and diversion works and on the main canal and its principal laterals. When existing canal systems are to be improved, the Government may subsidize the project to the extent of 50% of the cost of the improvement. The Government contribution in such cases is made by its undertaking the construction of the most important and difficult project features.*

GENERAL REMARKS.

The irrigation enterprise in the United States, as will be seen from what has been said, is either an aid in the development of the unsettled areas of the public domain or it is for the improvement of agricultural conditions in regions where the land is already privately owned.

The Desert Land Law, the Carey Act and the U. S. Reclamation Act are intended for the purpose of facilitating home building on the public domain. The State Irrigation District Law helps the private land owner. Of the former, the Reclamation Act permits Government aid to be extended. The State Irrigation District Law, the Desert Land Law and the Carey Act make no provision for financial aid by the State or by the Federal Government.

It is interesting, in connection with Government aid to irrigation and to agriculture, to note that in England, under the Act of 1907, County Councils are empowered to acquire and subdivide large estates and to give to the purchaser credit for

* See Irrigation Development, France, Italy and Spain, Wm. Ham. Hall, State Engineer, Cal., 1885.

80% of the purchase price at an interest rate of 3½% per year.

In Ireland large estates may be purchased or condemned by properly constituted Boards and are sold, after subdivision, in small tracts. Houses are built on these small farms and the new purchaser is charged 3% interest per year and ½% amortization. Tenants who desire to purchase the property which they occupy can obtain loans, not exceeding $1600.00, to the amount of four fifths of the purchase price, which loan must be repaid in installments within 30 years.

In Scotland a similar small holdings act is reported to be proving a great success.

In New South Wales, advances may be made to farmers up to two thirds of the value of unimproved land plus one half of the value of the improvements. The repayment of such advances is at the rate of 5% per year for 31 years, this being equivalent to about 3% interest on the money.

In Victoria, settlers are required to pay 3% of the purchase price at the time of the purchase and the rest of the purchase price at 4½% interest may be spread over a period not exceeding 31½ years.

In New Zealand, up to $15,000.00 may be borrowed for the improvement of land. The amount borrowed is repaid at the rate of 5½% per year (interest and amortization) for 36½ years.

Loans are made to the farmer under similar favorable conditions in Italy, in Hungary, in France, Switzerland and other countries. Provision is also made in nearly all of the more advanced countries for facilitating the borrowing of money at low rates of interest, through properly supervised and controlled banks.

The facts above cited relating to Government aid to the settler are referred to because the success of the irrigation project does not depend solely upon its physical features and adaptability of the soil to cultivation by irrigation, but also, and in no small measure, to the human element. The right type of settlers must be obtained where new areas are to be brought under cultivation, and the speculator must, as far as this is possible, be eliminated. Intelligent farming must be encour-

aged and should be made possible for the man of limited financial resources. Intense cultivation by the use of irrigation should be extended to the limit of the available supply of water and there should be no hesitation of providing Government aid to this end, even though this involves long time credit.

APPENDIX.

IRRIGATION STATISTICS—UNITED STATES.

The following tabulated information has been taken from U. S. Census Reports and is intended to give some idea of the extent of irrigation in the United States.

Information is presented for the arid region of the United States "held to include all sections of the U. S. where irrigation is commonly practiced in the growing of farm crops". Although some irrigation is practiced in the Eastern States, in connection with market gardening and the growing of fruit and special crops, the inquiry made by the Census Bureau did not cover this field.

The areas devoted to rice culture in the three States, Louisiana, Texas and Arkansas, are given below. The data here noted, being from the Census of 1910, do not bring the information up to date, neither does the information relating to rice culture include the large areas recently planted to rice in California, nor cultivation in the Southern States other than the three here named.

Rice Land Irrigation.

Number of farms	4,010	
Area of rice lands irrigated	694,880	acres
Area capable of irrigation in 1910	950,706	"
Area included in irrigation projects	1,134,322	"

Rice Land Statistical Summary.

	Louisiana	Texas	Arkansas
Acreage capable of irrig. in 1910	553,220	350,350	47,136
Total length of ditches (miles)	1,168	1,040	131
Reservoirs	104	21	19
Capacity of reservoirs (acre-ft.)	19,482	2,310	3
Flowing wells	....	1	....
Pumped wells	606	500	307
Pumping plants	1,007	575	315

Irrigation Summary for the United States (not including areas devoted to growing rice).

U. S. Census, 1910.

Total acreage irrigated	13,738,485	acres
Total acreage that could have been irrigated	19,334,697	"
Total acreage included in projects	31,111,142	"
Number of irrigation enterprises	54,700	
Length of canals and ditches	125,591	miles
" " main canals and ditches	87,529	"
" " lateral canals and ditches	38,062	"
Number of reservoirs	6,812	
Capacity of reservoirs	12,581,129	acre-feet
Number of flowing wells	5,070	
Number of pumped wells	14,558	
" " pumping plants	13,906	
Aggregate of power used in pumping	243,435	hp.
Acreage irrigated with pumped water	477,625	acres
" " from flowing wells	144,400	"
Aggregate cost of irrigation enterprises	$307,866,369	
Average cost per acre	$15.92	
" " of operation and maintenance per year	1.07	per acre

Extent of Irrigation According to Source of Water Supply. Summary for the United States.

Source of Water	Acreage Irrigated in 1909
By gravity from streams	12,763,797
" pumping from streams	157,775
" flowing wells	144,400
" pumping from wells	307,496
With water from reservoirs	98,193
By gravity from lakes	58,284
" pumping from lakes	12,354
" springs	196,186
Total	13,738,485

Reports from a total area of 3,426,241 acres indicate 4.8 acre-feet of water per acre as the amount of water diverted per acre of land irrigated.

The U. S. Reclamation Service reports 3.5 acre-feet in 1910 and 3.7 acre-feet in 1911 as the amount per acre delivered.

Adding 25% seepage makes the amount diverted from the stream about 4.8 acre-feet per acre.

Extent of Irrigation According to Character of Enterprise. Summary for the United States.

Character of enterprise	Acreage irrigated in 1909	Acreage capable of irrigation in 1910	Acreage included in projects
Carey Act	288,553	1,089,677	2,573,874
U. S. Reclamation Service	395,646	786,190	1,973,016
U. S. Indian Reservations	172,912	376,576	879,068
Irrigation Districts	528,642	800,451	1,581,465
Cooperative Enterprises	4,643,539	6,191,577	8,830,197
Individual and Partnership Enterprises	6,257,387	7,666,110	10,153,545
Commercial Enterprises	1,451,806	2,424,116	5,119,977

Acreage Capable of Irrigation in 1910, by States, According to Character of Enterprise.

State	Carey Act	U. S. Recl. Service	Irrigation Districts	Individual Partnership Cooperative Commercial	Indian Reservations
Arizona	....	164,500	....	202,181	20,974
California	....	1,200	249,108	3,320,580	3,490
Colorado	6,085	30,000	207,570	3,744,491	2,020
Idaho	742,618	113,000	177,900	1,333,901	21,540
Kansas	....	....	....	139,995	....
Montana	49,500	85,245	6,640	1,949,430	114,340
Nebraska	....	66,241	77,228	285,456	300
Nevada	....	90,185	....	747,396	3,381
New Mexico	....	21,467	....	598,760	24,743
North Dakota	....	12,096	....	9,821	....
Oklahoma	....	....	....	6,397	....
Oregon	65,500	45,319	1,500	717,768	439
South Dakota	....	47,568	....	80,863	50
Texas	....	....	....	340,641	....
Utah	20,000	....	8,455	1,135,191	86,600
Washington	....	74,500	....	346,014	50,000
Wyoming	205,974	34,869	27,050	1,322,918	48,699
Total	1,089,677	786,190	755,451	16,281,803	376,576

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DISCUSSION

Mr. Gideon. **Mr. Abraham Gideon,*** M. Am. Soc. C. E. (verbally), stated that the problems discussed in the author's paper are not confined to irrigation engineering, but apply also to general hydraulics and water-supply, and that the points raised extended to all activities of the people. While part of the statements are somewhat revolutionary, they are in the right direction. The speaker stated that he is not a socialist but believes we are coming to greater State control. Greater State control is now coming into use in the Philippine Islands. There the Government is taking up the development of irrigation works and is finding that Government assistance is required in the development especially of the sugar industry. The Government is now extending loans to certain sugar mills on such a basis as is recommended in the author's paper. Government engineers investigate the conditions of the project, and guarantee the interest and principal which are to be repaid by the owners.

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Paper No. 35

ECONOMIC ADVISABILITY OF IRRIGATION.

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Does irrigation pay? This is the commonplace way of summing up the central idea involved in a discussion of the economic advisability of irrigation. While some engineer may say that this question is one for the financier or economist and not for the designer and builder of works, yet a broad conception of the duties of the engineer inevitably leads to the conclusion that it is part of his business to be sure of his foundations in this regard. If these works as planned and completed by him are then found to be not financially successful, or not economically sound, he necessarily loses in the opinion of his fellow men. To put it in another way, the business of the engineer is popularly supposed to be that of creating by the use of a dollar those results upon which the less able man would spend two dollars or more. If, however, the result of the dollar's expenditure is not capable of returning a fair interest and profit, then the engineer's reputation must suffer with that of others concerned.

Continuing into the search as to whether irrigation pays, it is at once seen that there are many paths which may be followed. How much does it pay? To whom do the profits go? How well are they distributed among the investors or the farmers? Or do they go largely to the general public? Here again, the engineer may say that he has no concern and that this is a matter for the investor. At the present time, however, where stagnation has followed active construction, it is encumbent upon the engineer, as a man of affairs, to inquire into the causes which have led to the cessation of such work and to try

to find out whether these causes are likely to be removed. He is also interested because one of the explanations given of the financial failure of great irrigation enterprises is that of poor engineering. This charge should be clearly met, and while it may be conceded at the outset that, as in every other line of human endeavor, there have been mistakes and bad judgment exercised, yet if it should be shown that these are as small or less in their effect than is usual in other enterprises, then we must seek still further to ascertain the real cause. It will not do to let the charge rest on the mere denial of the statement that engineering mistakes have caused failure, but the real reason for loss should be made clearly apparent. More than this, the conditions should be so well explained that it may be possible to remove the obstacles to further development and stimulate work on a more secure foundation.

It is the object of this discussion to endeavor to point out, concisely, the present condition of development of irrigation and to indicate as nearly as may be the principal economic reasons why irrigation has been and should be practiced, the causes which have led to the present condition of delay in entering upon or completing large works and some of the lines along which further progress may be expected.

NEED OF IRRIGATION.

The development of irrigation must rest on some well recognized human need. In this case, it is obviously that of the production of food, either directly by the raising of grains, vegetables and fruits edible by men, or indirectly by feeding forage crops to animals and producing milk, butter and other dairy products, as well as beef, pork, mutton and various results of the live-stock industry. Throughout the eastern part of North America, as well as the northern part of Europe, this production of food is possible without the artificial application of water, but over an area of approximately two fifths of the United States, as well as in portions of the older countries, notably those adjacent to the Mediterranean, crop production is impossible without the artificial application of water. Here the engineer joins hands with the farmer in securing a needed supply, by diverting water by gravity from the streams or by

pumping it; or he builds reservoirs, large or small, to hold the floods which occur occasionally, so that the life-giving waters may be had when needed. In the areas described, irrigation is a necessity, for without it agriculture is impossible.

There are, however, localities where irrigation, while not absolutely necessary, is of the nature of insurance. It enables the farmer during periods of occasional drought to increase his crop and relieves him from anxiety as to the fickle weather. He can plan his work and, whether it rains or not, will be reasonably certain of obtaining the necessary moisture. In the case of intensively cultivated lands planted in high priced vegetables or fruits, under ordinary fluctuations the crop might be worth, say, $100 per acre, but by having an adequate supply of water which can be applied at the right time the crop production may be doubled or trebled, thus justifying a large outlay for irrigation works even in countries where the average rainfall is large but the distribution irregular.

CAPITALIZING THE SUNSHINE.

If we go into the philosophy of irrigation we find that what really takes place is that by providing a water supply we are making available the power of the sun, the source of all life and growth. Along the Atlantic Coast and inland, if the farmer needs moisture for his crops, he must wait for the rainfall. This in turn means that, during the rainy or cloudy days when the rain does occur, the sunlight is partly cut off. In the arid West, however, where the sun shines brilliantly nearly every day in the year, there is no waiting for rain, and there is available each day nearly the maximum energy for plant growth. With the ability to apply water by irrigation when needed, either during day or night, then the plant can have needed moisture and at the same time have the full benefit of the sun's rays. We are thus enabled to put to use the full effective energy from the sun, and to this extent may be said to practice a certain kind of conservation.

VARIOUS VIEWPOINTS.

The economic advisability of irrigation may be considered from several viewpoints, the most important of which may be summed up as follows:

(a) That of the farmer or the irrigator upon whose success rests the ultimate value of the works.

(b) That of the landowner, as distinguished from the farmer, whose chief concern is in obtaining an increased price or rental for his land.

(c) That of the investor, by the use of whose money irrigation is made possible.

(d) That of the promoter or organizer of the work, through whose energy it has been possible to initiate and bring to completion the engineering and related operations.

(e) That of the state or nation, including the communities which are directly and indirectly benefited by the successful building and operation of the works.

Taking these in the reverse order from that just given, it appears that from the broad, public standpoint attention should be given to those considerations which lead to the upbuilding and strengthening of the social or political structure. Beginning with this wide-angle view, we will consider first the larger public aspect and then the more immediate and personal relations.

STATE AND NATIONAL CONCERN IN IRRIGATION.

The material welfare of any political or social organization is dependent largely upon the best use of the resources or opportunities which have been provided by nature. It is a well-recognized fact that where nature has done the most, man has done the least, and that the greatest progress has been made in those countries where, through some natural deficiency or obstacle, the energies of mankind have been stimulated. Thus it is that the highest development of agriculture arose, not in countries where nature had provided an adequate rainfall, but where it was necessary to supply the deficiencies by artificial application of water, as in the case of the lands along the Euphrates; also in the valley of the Nile and in other regions around the Mediterranean. Here were to be found the most lasting examples of high development of the arts and sciences. From these regions culture spread toward the north and was brought westward across the Atlantic and planted in the eastern or humid portions of North America.

With continued western progress we have come again to the restrictions set by aridity and are confronted by agricultural conditions such as were successfully overcome by the ancient nations of the far East. We bring, however, to this task not only much experience, but also modern methods and machinery which enable the engineer of the present day to accomplish results which in former times would have been impossible. The results, moreover, to the social or political organization, to the state and nation, are correspondingly increased. With the ability to construct large works economically and quickly, the natural resources in sunlight, water and soil, otherwise unavailable, are brought together, and wealth created by the wise manipulation of forces or materials, each of which in itself would be wasted. The hot and almost unbearable sunlight of the arid region is turned to use in maturing not one, but several crops a year. The destructive floods are restrained and employed in rendering fruitful the otherwise barren ground. The whole community is benefited, not simply by adding to the wealth of a few farmers; these men are enabled to produce crops from the formerly useless soil and to manufacture these into marketable products of meat, poultry, butter and eggs. They in turn become large consumers of manufactured products brought from other regions, thus affording opportunity for other industries in the mills, the mines and on the lines of transportation. More than this, the taxable resources are increased and the nation gains in financial resources and, in what is still more important and vastly more fundamental, namely, stalwart, self-supporting land-owning farmers.

The economic importance to the nation of the development of irrigation is best illustrated by the fact that the crops produced under irrigation in 1909 aggregated in value over $180,000,000, or an average of $25 per acre irrigated ($61.78 per hectare). The total amount of money then invested in the various irrigation enterprises was over $300,000,000. It is to be noted that these irrigation systems were by no means complete, and that, without considering the new enterprises, it was necessary to invest over one hundred million dollars to bring them to completion. In the same way, the average crop production

under irrigation, though far greater per acre than by "dry farming", was low, because of the fact that the lands were not all fully developed. If we should throw out of consideration the farms on which irrigation had just been begun or which were not brought up to fair condition of cultivation, the average crop production would be much larger; for example, in the State of Washington where the lands were more carefully handled, and largely in fruit, the average was nearly $50 per acre ($123.50 per hectare).

THE PROMOTER'S VIEWPOINT.

In considering the economic advisability of irrigation, it will not do to overlook one of the most important factors, namely, the organizer or promoter. This term has been used, occasionally, as one of reproach. It is frequently assumed that the promoter is concerned only in his personal reward and has little or no regard for the merits of his scheme, so long as it will be of immediate profit to himself. There have been and always will be promoters of bad schemes as well as good, but we should not condemn the promoter, simply because in the past so many of his schemes have turned out badly. Rightly directed, he is one of the most useful of men; if it were not for the optimistic, aggressive spirit of the true promoter, progress made would have been slow and halting.

In the past, there was a time when the promoter's profits, real or assumed, were so great that many men were tempted to take up irrigation enterprises with little knowledge or care for the real facts, so long as there seemed to be promise of return. The wave of enthusiasm has declined, however, and the old-time reckless promoter is left high and dry. Nevertheless, there has never been a time when the well-informed and honest promoter, guided by proper optimism, is more needed than he is at present, to organize and arouse interest in legitimate western development.

The attractions to the promoter are, however, not now as great as in former years. Then, it was generally stated that good arid land could be had for from $1.25 an acre to $5 an acre, ($3.09 to $12.35 per hectare), or thereabout, and that water could be provided for this land at a cost of, say, $25 an

acre ($61.78 per hectare); also that the land thus reclaimed at a cost of, say, $30 an acre ($74.13 per hectare) could be readily sold for three or four times the cost. There was apparently a huge "melon to be cut" by the promoter and the investor. The excitement aroused by these large prospective gains swept men off their feet and schemes now regarded as visionary were eagerly entered into, the excitement rivaling that of the days of John Law and the Mississippi Bubble. A few promoters made large fortunes, on paper at least, but it was soon realized that the irrigators could not make the payments agreed upon, and glittering schemes of continued development sank into disrepute.

This stagnation should not continue indefinitely; there are opportunities for irrigation development which should be attractive to a man of vision, one who, warned by past experience, can avoid the weaknesses of earlier propositions and can erect his works on well-conceived financial and engineering lines. For such a man there is opportunity to initiate great works and to receive proper remuneration. The large, immediate gains, however, cannot be legitimately had, but there is reasonable hope of fair returns along safe business lines, as in other well conducted enterprises.

THE INVESTOR.

The man who supplies the money for irrigation development in the future can have at his command a wide range of experience accumulated in recent years. He should be able to discriminate between the sound and the visionary schemes, as there is now available a vast collection of facts relating to successful and unsuccessful enterprises. It is of public importance that the prospective investor be thus well informed, not merely for his own benefit but, more than this, to encourage others to enter upon this important work of western development. Any loss to the investor falls not merely upon him but, indirectly, upon whole communities, in discouraging the extension of the works or the taking up of new and important projects. The success therefore of the promoter and of the investor whom he interests in the work is not merely a personal affair; it is one in which the state and nation may take

a proper interest, as leading to a larger development and use of the otherwise untouched resources of the commonwealth.

It is a matter of public importance that the investor be shown that there exist fair and safe opportunities for profitable use of his money, in storing the floods and in diverting the otherwise waste waters to lands, which, without this added moisture, are unproductive. It should be demonstrated that there do exist such opportunities and that they are sufficiently attractive in the way of reasonable profit and interest to induce the investment of the savings of men and women throughout the country. If proper precautions are observed, there is no reason why, under normal conditions, irrigation investment cannot be made as attractive as railroad or industrial securities, the principal condition being, as before stated, the assurance of safety or of the "integrity of the project".*

The economic advisability of irrigation from the standpoint of the investor centers upon this one question: Is it a safe investment? The answer is that, as in any other complicated business, it can be made safe by the exercise of good common sense and suitable precautions. Failures in the past have been due to an ignorance of conditions, now better understood.

In the case of irrigation bonds, for example, it may be necessary, in order to make these more attractive to the investor, that some of the states safeguard these to a larger extent than in the past, not only by throwing added protection of law about the bonds, but also by going still further and

*The underlying principle of any plan adopted should be one which shall have the effect of guaranteeing the integrity of the project, that is to say, sufficiency and reliability of water supply, good engineering, and an economical expenditure of funds, with the elimination of any promoter's profit, to the end that irrigation securities shall become gilt-edged, with consequent low interest charge. It is believed that if a plan can be devised through cooperative State and Federal legislation, such that the Government shall pass upon the sufficiency of the scheme, and if approved, shall thereafter supervise or perform the heavy construction on plans and specifications theretofore agreed upon, the cost to be secured by a lien which can be effectively enforced, private capital would have that guaranty of stability which would induce its investment in the securities of such projects. (From Report of Clay Tallman, Commissioner of General Land Office, 1914, page 29.)

adopting methods which may be comparable to those of the pure food laws, or so-called blue-sky enactments. In certain states it may also be desirable that the whole course of legal procedure, by which collection may be enforced and the payment of the debt assured, may be more thoroughly worked out, leaving as little question concerning the validity of irrigation bonds as there is concerning those of school districts and municipal organizations.

The real safeguard, however, behind all of these investments is the determination of the question as to whether or not the farmer, who is living upon the irrigated land, can and will pay his debts. The assumption made, that, as a matter of course, he can do so if water is provided, must be thoroughly tested. Experience has shown that it is not enough to bring water to arid land but that there are innumerable other conditions which must be studied, beginning with the character and ability of the settlers themselves and continuing through all of the elements of soil, climate and markets. If for any reason a whole community neglects or refuses to use the irrigation works, as has happened because of misfortune or of some more or less real or fancied grievance, there is little, if any, redress, legal or otherwise. It is practically impossible to sell out or dispossess a whole community, and the attempt to enforce legal rights or coerce any considerable number of farmers leads to unsatisfactory results. Success can be attained only by cordial cooperative work, and not by opposition.

THE LANDOWNER.

Much of the unutilized irrigable land is still in the hands of the United States and is open to entry and settlement under the terms of the public land laws. A portion of this irrigable land is under the control of the various western states, but the greater part, especially that along the rivers and in the broad valleys, has passed into the hands of individuals. In considering, therefore, the advisability of irrigation, one of the most important factors is the attitude of the private landowner, as distinguished from the state or national interest. There was a time when irrigation projects could be laid out almost exclusively on public lands and when it was not necessary to

consider these complications of private ownership. Now, however, the vested rights, even in the arid regions, have become so important that the individual or corporate landowners practically control the situation; their active cooperation is necessary in the success of any new large irrigation enterprise. Their immediate interest is often diametrically opposite to that of the public in general, and what seems to be their inordinate greed for quick profits has defeated many meritorious schemes for the upbuilding of the country. This condition is not true of all or even of the majority of landowners, but there is enough of selfishness or indifference to make exceedingly difficult the task of the organizer of irrigation works.

The owners of arid land, as a whole, have a proper interest in irrigation development and in securing to themselves a reasonable increase in the value of the land due to the introduction of water for irrigation. Many of them have been dazzled by the assumed great profits and have initiated irrigation enterprises, or joined in them, with the hope of securing a gain of several hundred per cent from their original investment. There has been an attempted speculation in irrigable lands, which is at the base of much of the discouragement and failure which have resulted.

Landowners have put such prices on their lands as to discourage the real homeseekers. Thus, an inflation of land prices, under conditions where there has been no corresponding addition of real value, has been the great obstacle to sound development throughout a great part of the arid West.

In many instances the lands have been sold to newcomers, who, with more enthusiasm than capital, have paid out their last dollar in making a first payment and who have agreed to make deferred payments at an interest rate which perhaps originally was 8%, but has been gradually raised to 10% or 12%, or even more. This results in a burden which cannot possibly be carried by the ordinary tiller of the soil, particularly under pioneer conditions. It is these heavy interest charges on land purchases which are causing the greatest distress in the irrigated region. Moreover, the irrigators are usually land poor, in the sense that each man is attempting to

handle more land than he can fully utilize with the labor and capital available and is paying the heavy interest charges for this excess land, these eating up all possible profits.

FARMER OR IRRIGATOR.

On the back of the farmer rests the entire superstructure of irrigation development. Unless he succeeds, not only in making a living, but in showing a reasonable gain at the end of the year, the works and the investment in them cannot be called a success. In other words, the landowner, the investor, the promoter, the state and the nation, all look to the farmer to justify the effort made in irrigation development. The engineer who plans and builds the works sometimes forgets this fact, or, at least, considers it none of his business; but with wider view of his opportunities and responsibilities, he is beginning to appreciate more and more the fact that he has a duty in seeing to it that, so far as lies within his power, the works are planned and built with primary consideration of the farmer's need and personality.

In spite of the fact that the success of the irrigator is at the base of success in all irrigation development, there has been general neglect to consider his true economic relations to the work. This is perhaps due to the fact that those matters of largest and most general interest which are everybody's concern are left to the last. We are apt to spend time and money studying the health of the pigs on the project rather than that of the children. In the same way we have given more thought to the legal status of the irrigated land than to the ability of this land to produce crops.

It has been accepted as matter of common belief, practically unquestioned, that when water should have been provided the desert would "blossom as the rose" and that the farmer would immediately be attracted to the irrigable land and would begin to produce valuable crops, starting with the very first year to make substantial payments. This unquestioned belief has resulted in an enthusiasm for irrigation investments which at one time became almost hysterical; otherwise cautious investors, neglecting the thorough study of the problem from the standpoint of farm values and earnings, have

rushed into chimerical schemes. The stories, many of them true, of great individual success in irrigation, have been considered as typical of all irrigators, and the discouragements or partial failure of many of the pioneer homeseekers have been overlooked. We have often been misled in the past by confusing the possibilities of the soil and climate with those of the owner or tiller of the soil. The land may have great value in itself, when compared with land similarly situated elsewhere, but the particular owner or group of owners with the surrounding limitations and lack of capital may not be able to realize upon the intrinsic value of soil and climate.

One of the questions for the engineer to consider in planning the works is as to what is the true condition of the settlers and their families for whose use the works are to be built. It is not easy to ascertain this fact because of the condition above noted, that everyone has made certain broad assumptions and has not considered it worth while going behind these. In the attempt to do so, we are confronted by the obstacle that there are few reliable facts. It is true we have census statistics showing land values, crops and investments. These results are given in large units, usually by counties, but none of these has been worked up in such detail as to illustrate the important points as to the true condition of the irrigator.

The Reclamation Service has initiated a somewhat detailed study of conditions on the projects which have been built by the use of public funds, and while these are incomplete, yet they reveal for the first time certain general conditions which before were little known or appreciated. The Department of Agriculture also, through its Office of Farm Management, has begun to bring together results of careful studies, analyzing the condition of the farm from a business standpoint and bringing out clearly the fact that the average farmer obtains for his investment and labor about 5% on the capital involved and an earning about equal to the wages of a day laborer. If he employs farm labor, the cost, under prevailing conditions of high prices and inefficiency, may eat up a great part of these scanty earnings.

These considerations of cost and returns from the irrigation farm are fundamental in any discussion of the economic

advisability of irrigation, and it may be said that the study of irrigation farming as a business should be a part of the irrigation engineer's duty as well as that of the promoter and investor.

To get at this, we must utilize such data as are available as to the outlay or cost of the farm and necessary equipment, the related expenditures of taxes and water rates, the returns in the way of crops, necessarily governed largely by market conditions, the annual profit and the gradual increase in farm values.

COST OF IRRIGATED FARMS.

The ideal situation, and the one which has stimulated public interest in western development, is the assumption that certain irrigable lands can be had for little or nothing and that with the expenditure of, say, \$25 an acre (\$61.78 per hectare) in providing water and an equivalent amount in labor of the owner in subduing the soil, there would result irrigated fields worth at least \$100 to \$150 per acre (\$247.11 to \$370.67 per hectare). This shows an apparent profit of \$50 per acre (\$123.56 per hectare), more or less. This alluring price has been sufficient to attract large investments made in the hope of quick returns. The unfortunate feature, or the one which has done much to produce the present state of stagnation, is that the promoters or investors have endeavored to obtain for themselves at once this apparent margin of profit, and without even waiting for the work to be executed. In other words, what should be an increment of value after large investments have been made and after the farm is reclaimed, is seized upon in advance. The homeseeker is induced to agree to pay for the raw, unirrigated land, not what it is then really worth but prices of from \$50 to \$100 per acre (\$123.56 to \$247.11 per hectare), or even more. He is paying not for what has been actually accomplished but for what he hopes may come. It is this advance profit charged for the raw land which is most detrimental to success.

Where the conditions are such that the irrigator can obtain the raw irrigable land by homestead entry, he then can start without this great handicap. But, as a matter of fact, many persons who have obtained these lands are swept off

their feet by the prospect of immediate returns and are tempted to sell relinquishments, believing that they can profit more largely by raising the price of the land than by the more laborious process of raising crops. Thus it results that the man who ultimately pays for land and water is usually not the original entryman but a man who is really paying to such entryman and to his successors a heavy bonus for the privilege of getting title to the land.

Investigations made show that throughout the arid region the prices for undeveloped land which is susceptible of irrigation have ranged, as above stated, often from \$50 to \$100 per acre (\$123.56 to \$247.11 per hectare), the purchases being usually made on installments, with about a fifth or a tenth down and the balance in from 5 to 10 years and at interest rates rarely as low as 6% and more often at 8% and upwards.

The taxes on these lands are necessarily large, because the country is in a pioneer condition. Everything must be done; roads must be built, schoolhouses erected and provision made for county and other officials. Everything is new and untried, and there is general lavishness in these matters, such as accompanies an influx of population. In the case of homestead land for which patent has not been issued, taxes usually cannot be levied on these lands, but the improvements may be assessed. The valuation is usually low, being a half, or even much less, of the sale price, but the tax rates may run as high as 2%, or more, on this valuation.

The large expense, however, on the raw land, after the purchase price, is that of leveling and subduing the soil. In some favored areas where the surface has not been cut by winds and rains and where there is little vegetation the cost may be as low as \$10 or \$15 an acre (\$24.71 to \$37.07 per hectare). In other cases, such as on the rich alluvial soils near Yuma, Arizona, the removal of the heavy growth of cottonwood and willows and the bringing of the surface to proper level may cost \$50 an acre (\$123.56 per hectare), or even more. This cost, however, is largely that of the labor of the owner himself and usually requires little cash outlay.

The equipment of the farm may consist, at first, of a few tools and domestic animals; the owner may live in a rude

shack, built by himself, and his animals may shift for themselves in a corral. These conditions, however, can be only temporary. The needs of the family, as well as those of the farm, require a constant outlay, so that for a fairly well equipped farm the total outlay will in time aggregate over a hundred dollars an acre, including in this the domestic animals, implements, barn and house. Various estimates have been prepared, of which the following may be considered as fairly representative for a 40-acre (16.19 hectare) farm, with small, with fair, and also with what may be called a good equipment.

Cost of Improvements, Equipment, Stock, Feed, Seed and Trees for a Forty-Acre Irrigated Farm.

Item.	Small.	Fair.	Good.
Buildings:			
House	$400 (a)	$600 (a)	$800 (a)
Barn	100	150	200
Granary or fruit shed	125	125	125
Other buildings	250 (b)	300 (b)	360 (b)
Fences	100	175	250
Well	75	75	125
Ditch structures	50	75	75
Total	$1,100	$1,500	$1,935
Equipment:			
Soil tools	$70	$75	$190
Seeding tools	15	80	140
Harvesting tools	20	110	255
Sprayers	20	35	45
Harness	45	50	90
Vehicles	150	240	340
Small tools	15	20	25
Total	$335	$610	$1,085
Stock:			
Horses	$300	$300	$375
Cattle	150	200	250
Hogs or sheep	60	80	100
Fowls	25	25	25
Bees	10	20	20
Total	$545	$625	$770
Feed	$845	$820	$580
Seed and trees	150	150	150
Grand total	$2,975	$3,705	$4,520

(a) These figures may be reduced by about $200, particularly for the warmer climates, if the settler is disposed to be contented with the accompanying inconvenience.

(b) These figures may be reduced by about $150, for the warmer climates and for very meager conveniences.

The above table was compiled by F. W. Hanna, Manager of the Boise, Idaho, Project.

FARM RETURNS.

The returns from an irrigated farm are: first, the use of the home and then a large part of the food of the family; next, the products which may be sold. The value of the latter depends very largely upon market conditions, and this in turn upon transportation. A study has been made by the Office of Farm Management of the Department of Agriculture as to what the farm contributes directly to the farmer's living.

Ten typical localities were studied, of which, however, none are in the arid region; but it is believed that the results do not differ very widely from those which prevail throughout the West and serve to give definiteness to the general results obtained by the Reclamation Service from its 16,000 irrigated farms. These show that of 483 families in 10 representative agricultural districts, the average annual value of the food, fuel, and use of the dwelling in families of between 4 and 5 persons is between $400 and $500 per family, averaging a little over $90 per person.

Taking the 51 families studied in Iowa as possibly representing most nearly the western conditions, the average per family of 4.4 persons was $485 per family, or $115 per person. Of this $115 per person, $70 represents the cost of food and $38 the value of the house rent.

Taking the total expense for the food of the farmers' families, as noted above, nearly two-thirds in value was furnished by the farm, the principal purchases being groceries, such as tea, coffee and flour, salt, etc. From this it appears that, as above stated, the first and most immediate returns from the farm must be considered those of shelter and food.

Next in importance is the item of interest on the investment, as it is assumed that the amount of capital tied up in the farm, the buildings and equipment should return, within the arid region, at least 6%. The ordinary interest rate is 8% and taxes are high, so that unless at least 6% on the investment is earned, it is obvious that the farmer would be better off financially if he utilized the money invested in the farm in loaning it out on mortgages. In the estimates, therefore, of the returns from the farm, it is assumed that the owner is entitled

to 6% interest on the true value of the investment which he has made. This investment is not necessarily the amount of money or labor expended, as much of this may have been unwisely employed and, if so, should be considered as a loss, as in the case of a dead horse. The fact that several hundred dollars were invested in the horse or in unwise improvements on the farm does not justify a charge for interest on the whole amount spent.

The next item of return, in addition to home, food and interest on the investment, is the increased value or net profits due to the owner's labor. Here is where the greatest difference exists between assumed and real conditions. It has been assumed in the past that great profits must inevitably accrue to the irrigator, and that through his efforts crops of unusual value would be produced and his farm brought up to a degree of productivity which would yield him large returns for his efforts. The average condition has been found to be disappointing, and in this disappointment is found the cause of most financial failures of irrigation schemes. While, as before stated, the reason for these failures has been attributed in some cases to reckless promotion, to poor engineering or to improper financing, yet behind all these is the fundamental fact that the earning of the average irrigator, as well as that of the average farmer, is barely above that of the day laborer. Of course, as stated elsewhere, there are exceptional cases, but in considering the economic importance of irrigation we must give weight to the average and consider that "the exception proves the rule".

The average earnings of the farmers have been discussed by the Office of Farm Management in the Department of Agriculture in various publications, notably in a study of a group of farms in the central part of Utah, where a careful analysis of cost and returns has been made, the only one available, at present, for the arid region.

These returns relate to 69 farms, which are fairly representative of conditions throughout the arid regions where the pioneer stage has been passed. The average size of these 69 farms was under 50 acres, and the crop area about 30 acres (12.14 hectares). The average capital invested was $9000, or,

in round numbers, $175 per acre, including all improvements. The receipts were slightly under $1500, and out of these were paid a little over $600 for expenses, leaving a net farm income of nearly $900, of which the labor income was figured at a little over $400, leaving, in round numbers, $500 for the earning of the investment and of the farm itself.

Taking out of the 69 farms a group of 30, which are devoted mainly to fruit and the raising of sugar beets, we have an average size of 60 acres, of which a little over 40 acres are cropped. The capital invested is a little under $12.000 and the receipts approximately $2000, with an expense of $950. leaving a farm income of about $1000, of which the labor income is something over $600.

MARKETS FOR IRRIGATED CROPS.

The returns to the farmer are governed largely by ability to market his crops. The question of markets is tied up very closely with that of transportation. The evolution of an irrigation project brings out clearly a condition which has often misled investors on the economic feasibility of their scheme. When the project is started and during the first year or two after water is brought to the land, there is usually a large immediate demand for the products of the soil. The contractors on the work, the small towns or mining camps in the vicinity, pay large prices for the limited supply of alfalfa, vegetables and fruits. On the basis of these prices good profits seem assured to the irrigators.

There quickly arrives a time on each project, however, when there is a sudden drop in prices. The contractors finish their work on the irrigation system and on the adjacent railroads, and thus much of the immediate market is removed. The aggregate farm products quickly overtop the limited demand and a phenomenon occurs, surprising to the local people, but plain when studied. The price of alfalfa for example, up to this time, has been that of the forage in distant markets, say, $10 per ton plus the cost of transportation, say, $4, making the local market price for alfalfa $14 per ton. As soon, however, as a larger tonnage is available locally than is needed for home consumption, then the price is fixed by the ability to dis-

pose of the excess in more remote markets, and instead of $10 plus, we have $10 minus $4 freight, or $6 per ton for the alfalfa loaded on the cars. This very simple conception has been overlooked in most prospectuses of irrigation projects.

The first necessity after the ground is subdued is that of providing a market for the crops. This brings in immediately the question of cooperation among the producers in handling these crops. In the case of certain specialized lines, such as high grade fruit, oranges or apples, there have been worked out several successful organizations, but in the ordinary crops there is yet much to be done. Cooperation among men coming from all parts of the world and with widely differing experience and traditions is a matter of slow growth. It succeeds best where the men and their families have known each other for years, or even generations, and where there are the same ideals and moral standpoints. Cooperation, while developed primarily for financial reasons, is largely controlled by the pyschological attitude of the people and cannot thrive where there is an ignorance of each others' minds and motives, such as leads to doubt or suspicion.

The best market for crops is that which results by the manufacture on the farm of the raw products into the highest possible degree of concentration or value. For success, a farmer under irrigation should not only diversify his products but accompany this diversification by what is equivalent to a series of small manufacturing operations. Further, to profit by these operations he must be guided largely by the same principles which lead to success in other small factories—namely, by careful utilization not only of the material but also of the time of himself and of his family; his largest profits coming from working into profitable form what in a factory are called the by-products.

While there may be small profits in raising ordinary field crops, yet by using as much as possible of the forage and grain in feeding animals; in putting to use, in the proper manner, the time of the children in caring for the hens and smaller domestic animals; by working up the otherwise spare or waste products, and turning to account even the weeds, in the production of mutton, pork, beef, milk, butter, poultry and eggs, the careful

farmer is able to show a net return for the entire family which justifies some of the assertions made of the great profits from irrigation.

PROFITS.

The economic advisability of irrigation lies in the answer to the question first asked, namely, as to the profits. It is only by a comparison of the cost of producing crops with the net returns that this question can be answered. As has been shown, the average net profits are far smaller than has been anticipated; but enough has been learned to show that with the energy and thrift which are necessary for success in almost any line of endeavor, the farmer on irrigated land has the possibility of increasing his profits to a large degree, and with greater assurance of continued success than in many other enterprises. He is sure of a home and food for the family, and, with the comparatively dense settlement of an intensively cultivated region, he can enjoy many conveniences, such as graded schools —and often electric light and power. He also has the opportunity to secure constant and increasing profits, dependent almost wholly upon his initiative and strength.

The question of increasing the profits is one which, as in almost any other business, is dependent, first, upon the capital available, and, second, upon the skill with which this is used. There are certain limits, however, which define the size of the individual business. In the case of ordinary farming in the East, it has been found, for example, that about 200 acres (80.94 hectares) representing an investment of, say, $20,000, is the most advantageous; the extent of land and amount of capital being most nearly adapted to the strength and ability of the good farmer. Beyond this limit, it is necessary to employ hired labor, and often at a loss. Farming is unlike manufacturing in that it has rarely been found profitable to work men in gangs or large organizations, and attempts to do so have usually proven unprofitable.

ECONOMIC FARM AREA.

What is the size of a piece of raw or partly improved land which yields the best results for the average newcomer on an irrigation project? Is it 20 acres, 40 acres, or 80 acres, or more

or less? The answer is fundamental in any so-called "back to the land" movement. In this connection, it must be kept clearly in mind that we are not concerned with the most generally discussed side of this problem, namely, the largest or most economic yield per man, nor even the largest yield per acre. It has been habitual for some writers on the subject to dwell on the larger crops per acre obtained under irrigation—usually in countries where labor is cheap and land prices high—and where the farmer or irrigator has behind him not only years of experience but also ample capital and assured markets. On the other hand, we have pointed out as the ideal agricultural conditions the well-equipped farm of, say, 200 acres; where, though the product per acre is less, the return per man is greatest.

Neither of the above noted quite fits the conditions usually imposed in the considerations of the economic advisability of irrigation. The great benefits of irrigation are inseparably connected with somewhat peculiar limitations. These are those coming from the fact that the desirable or obtainable settlers comprise families rarely having adequate capital to start on an ideal scale the new business—that of irrigation farming. If they had enough money for this purpose, as a rule, they would not try their fortune in this new locality. Evidently their limited resources in money and labor should be carefully conserved and not dissipated over a large area—nor crushing debts incurred in starting what is to them an experimental occupation. Until the soil, the climate, the markets are well known and thoroughly proved, their efforts must be largely experimental and partake almost of a game of chance. For this and other reasons, the smaller the area of the new farm, within reasonable limits, the less the risk, the better the preparation of the soil and the more certain the procuring of food for the family, with a possible surplus to work up into most valuable forms for sale.

Enough land should be had to fully absorb the energy of the family, in the same way that the wagon and load should fit the strength of the horse. For best results, this should neither be too large nor too small. As previously stated, the common error of the inexperienced irrigator is to attempt to

handle too large an area of irrigable land, with consequent diffusion of energy followed by discouragement and loss of time and money. His earnings are eaten up by interest charges, water rents and taxes. On the other hand, by concentration of effort, not carried too far, a small tract of new land may be properly leveled, subdued and brought to a high degree of productivity with corresponding larger net profit, consideration being given to the capital employed.

If the irrigator had ample means, he might successfully attempt large areas, but the limiting condition in considering the economic advisability of irrigation, and its expansion to new areas, is that of securing success for the pioneers, who arrive, usually, with little money and even less practical experience in the conditions to be met. If these first comers succeed, the rest is relatively easy. Experience has shown that, under conditions which generally prevail throughout the arid regions, the pioneer family makes a better start on 40 acres than on 80 acres, and under favorable climatic conditions may show larger returns for the time and labor invested, on 20 acres, or even less. Later, when some capital has been acquired and profitable crop methods and rules established, then, and not until then, will it be practicable to acquire and farm larger areas.

VALUE OF IRRIGATION WORKS.

The preceding discussion leads up to the consideration of the true value of the irrigation works already completed, and of others partially built and now lying dormant. Millions of dollars are tied up in such works and even larger aggregate capital is held unproductive in lands, improvements and dependent industries awaiting the revival of irrigation. One of the largest questions of importance to the investors, to the land owners and to the state and nation, is that of getting these irrigation systems into full use. The first step is to find out what these works are really capable of accomplishing. Disregarding what they may have cost, the real question is as to what they are now worth. This is met largely by the second question, What do they earn or what can they be made to earn?

We formerly assumed a large earning power on the part of the irrigators, and consequently of the irrigation works. Later knowledge has shown that great profits have not generally resulted to the farmers, but we must not go to the other extreme and say that, therefore, the works are valueless. There is a sane, middle course, and one which can be found only by careful study of the facts now available. It is by such efforts that we should now examine into the situation and devise sound lines for future progress, to demonstrate that it is possible to build and operate large irrigation systems with reasonable profit and interest to the investor, whether an individual or the State. In the case of the latter, however, the profit may be indirect, but none the less valuable. To show such profit, a correct system of valuation must be had, and one which will enable an annual statement to be prepared of the profits and loss of the system. Such valuation must take into account not merely the physical conditions or cost of replacement of the existing works, but, more than this, must assemble the facts as to the farm values, investments and net earnings of the farmers served by the works, or who may be thus served; for it is upon their financial success, in the long run, that the earnings of the irrigation system depend. In the case of undeveloped or uncompleted irrigation works, such information should be had, not from theoretical consideration as to what ought to take place, but, on the contrary, from actual facts as to achievements on irrigated farms and irrigation systems similarly situated.

It is no longer proper to assume that if irrigation works are well built and bring water to arid land, then the rest of the problem is solved. We cannot pass over, unquestioned, the assumption that the farmers can and will make use of the water provided and make payments for the land and water. In the past any doubts expressed on this point were treated with scorn, as showing the ignorance of the inquirer as to the whole subject of irrigation. Now, however, we have come to appreciate the fact that the correct answer to these questions as to the possibility of utilizing the works when completed, underlies the whole economic advisability of irrigation. It is surprising to learn how little is really known on this vital

point and how generally the promoters and investors in irrigation works have allowed themselves to be misled on this fundamental point.

Not only should we have more facts, as above noted, as to the value of the works, but, for effective use by engineers and the public, efforts should be made to secure greater uniformity in presentation of reports on irrigation projects. In the past, each investigator has followed, as a rule, some system or scheme which has appealed to him personally. As a result, he has often omitted many essential facts, and the results of his report when completed are not immediately comparable with those of other similar works.

The form and arrangement of irrigation reports must necessarily be somewhat arbitrary, as no two projects present precisely the same problem; but it is possible to agree upon a definite schedule or form of presentation such as will obtain the best results for most projects.

The schedule should cover all important details, beginning with the farmer—the soil, crops, climate, markets, water-supply and structures—arranged in some simple logical order, and should lead up to a definite conclusion to be embodied in some numerical expression as to the value or extent of the principal factors. These conclusions, which are the fruition of the entire work, must flow out of the facts presented in detail; but to arrive at these it is necessary to have agreed upon, in advance, a logical scheme of valuation; one which will be comparable with others and, aided by such comparison, lead up to the answer to the question, Is the project profitable or can it be made profitable? remembering, however, that the project which may be profitable from the state or national standpoint may not be from that of the private investor, who must be assured of a continued interest payment upon the investment and the ultimate return of his money with reasonable gain.

The statements made in the preceding pages are summarized in the following words:

CONCLUSION.

(a) Irrigation is of prime economic importance to the community, state, and nation by enabling a complete agricultural development of the arid lands and by insuring immunity from loss by drought on other lands, thus making possible intensive cultivation and a maximum annual crop production.

(b) The material benefits to the community are not measured by the crop production alone, but by the stimulation of other industries, such as stock-raising, mining, manufacturing and transportation.

(c) A still greater benefit to the nation, rising far above material wealth, is that coming from the increase of an intelligent and prosperous rural population, who are not merely producers of food for other people, but who, living in the open, contribute most largely to the best elements of citizenship.

(d) The stagnation which now prevails in irrigation development is due to lack of proper recognition by engineers and investors of the fundamental economic conditions governing the profits of the individual irrigator—and can be relieved only when these conditions are more fully recognized and used as guides in future projects.

(e) The recrudescence of irrigation will come about when, for each enterprise, it is demonstrated, on the basis not of theory but of full study, that each irrigator can and will be able not merely to feed his own family, but to sell at a profit enough of his products to pay for the cost of irrigation.

(f) If it is fully demonstrated that he can pay these costs, with a small profit, in ten or twenty years, or even more, and with a reasonable rate of interest, then private capital can be depended upon to execute the works.

(g) If, however, it appears on complete investigation that he cannot hope to pay adequate profit to the investor nor interest charges on the investment, for several years—then the importance of the project to the community may justify the incurring by the people, state or nation, of certain liabilities.

(h) This public, or semi-public, assumption of liabilities may take the form of self-taxing irrigation district organizations—or of loans of public money or credit, such as by the

use of the Reclamation Fund of the National Government or the proposed issue of bonds guaranteed in various forms.

(i) Where adequate real security now exists in established towns, or industries, surrounded by partly developed agricultural lands, such irrigation districts, formed and guided by wise state laws and administration, are practicable and economically advisable. In those cases, the needed funds for development may be had by bond issues under state supervision; all of the property benefited, whether directly or indirectly, being held as security for these bonds—and taxes collected in the manner usual for school or municipal districts.

(j) When such security does not exist but will be created in time by the building of irrigation works and the improvement of the farms, then it may be justifiable and necessary for the public welfare that public funds be used to initiate the work and to carry it on to a time when there is created producing property of real value. Then the burden should be transferred to the local community, town and county—to continue the work under a suitable self-taxing district organization.

(k) The organization, whether corporate, state or national, which builds the large irrigation works and finances the enterprise,—as a further step in insuring the success of the investment,—must see to it that the settlers and farmers are enabled to obtain money or credit adequate to their needs while becoming established upon the reclaimed land.

(l) We are now at the threshold of the consideration of a broad public policy, upon whose adoption depends the continued development and use of the resources of a great part of the western states and of the nation. It is incumbent upon engineers, as thinking men and citizens, to give to the working out of this policy the same thorough study and elimination of fallacies as would be given to the foundations and plans of a great reservoir system.

(m) From such action on the part of the engineers and economists there will come about the larger appreciation on the part of the public of the economic advisability of irrigation, and the placing on a firmer basis of the financing of those works which lead so directly to the realization of the highest ideals.

DISCUSSION

Mr. Abraham Gideon,* M. Am. Soc. C. E. (verbally), stated that failures of engineering projects due to faulty economic considerations are not confined to irrigation alone. Five transcontinental railroads in the United States have also failed, due to the development of less traffic than was expected. Mr. Gideon.

Mr. P. M. Narboe,† M. Am. Soc. C. E. (verbally) stated that the question of what is economically advisable in irrigation development varies under different conditions. As in all engineering work, what may be economically inadvisable today may become advisable in a few years. In the earlier development of California, the cost of irrigation systems averaged $19 to $20 per acre, and at that time costs as high as $25 per acre were considered prohibitive. Very recently the state of California investigated the bonding of a certain irrigation district where the bonded indebtedness would be $107 per acre and where 80% of the land would require pumping water to a height of 450 feet and the remainder to a height of 650 feet. The cost of operation would be high, yet its inhabitants are convinced that it is economically advisable to make the development. Also, the State recently investigated another irrigation district where the present cost of the plants in use averages $115 per acre and where the operation cost is $47 per acre per year; yet the farmers there are prosperous. A few years ago this same land was offered for sale at $3.50 per acre. These examples illustrate the difficulty of giving a definition of what is economically advisable in irrigation-development. Mr. Narboe.

Mr. Elwood Mead,‡ M. Am. Soc. C. E. (verbally), gave another example of the uncertainty of the economic advisability of irrigation and its change with time. He states that fifteen or eighteen years ago a farmer at Billings, Montana, who had agreed to pay $10 per acre for a water-right was thought to be facing certain ruin, as it was not believed that the land could stand such a charge; at present much higher costs for water-rights are being paid in the same locality. Mr. Mead.

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Paper No. 36

DISTRIBUTION SYSTEMS, METHODS AND APPLIANCES IN IRRIGATION.

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INTRODUCTION.

In opening this paper, it should be said that the most important part of the distribution system is the farmer who is to use it. If the man is not successful, the project is a failure.

When an irrigation project is proposed or built, its primary object is to make homes on the land. There may have been other reasons for its construction, but unless the first is accomplished, no matter how well the project is conceived, or how much engineering skill is shown in its construction, it cannot be considered a success. It is regrettable that so many constructed projects have not been the successes they should have been or might be made, and it is therefore desirable that we examine into the secrets of success and the causes of failure with a view to remedying defects in the constructed projects and avoiding them in those still to be built.

THE SECRETS OF SUCCESS.

The secrets of success are not difficult to find; they are as follows:

First, and all important, a sufficient water supply.

Many projects have been constructed in the past with little or no attempt to ensure a sufficient supply of water for the irrigation of the lands. The necessary assurance that the available sources of supply are sufficient, can be attained only after observation covering a long period of years. Such work is beyond the resources of any private individual or corporation and should be undertaken by the governments.

Second in importance, though not absolutely vital, is good construction. This must be considered as a term of which the meaning is relative. A quality or character of construction which would be considered necessary in an old and established country might be sinful extravagance under pioneer conditions. Many of the failures in new countries may be charged to setting too high a standard for the construction of the works. New countries find it difficult to raise capital but have little trouble in paying maintenance charges, and even if the ultimate cost is higher by reason of temporary expedients in first construction, the project may be better off in the long run. This is also true in a divided sense. It may pay to adopt a high standard in the large main arteries of the project on which the settler has to pay for the maintenance, and a much lower one in the distributaries where he does the actual work himself.

Third in order, and quite necessary to success, is a well organized system for transporting and delivering to the settler, the water on which he depends. Mere capacity to deliver water matters little to the success of the project. It must actually do so in the proper quantity and at the time when it is most required. It is true too, that while a well organized operating force can go very far towards success, it cannot go all the way. Quite as much, or even more, depends on proper use of the water after it is delivered. To this end the settlers and the canal management must cooperate.

Where irrigation by flooding is the general rule, it is to the settler's individual interest that he obtain his water in as large a ''head'' as possible at certain critical times, but it is manifestly impossible to build the whole canal system large enough to provide such a head for all the settlers at the same time, hence, it is to the interest of the community that the

available supply be made to go as far as possible without restricting any person in the use of a practicable irrigating head. Evidently, these two requirements conflict and can only be reconciled by cooperation. Let the settlers so prepare their land and diversify their crops as to be able to take turns at the available supply, or else let them learn to get along with a small uniform head delivered continuously. Neither is impossible and both have been worked, but it is generally conceded that the former is the preferable arrangement.

GOOD DESIGN.

It is also evident that proper design of the distribution system is of very great importance in successful management. The best of management can make but a poor showing with a badly designed distribution system, while on the other hand, with a perfectly designed system, even the worst management would be hard put to it to find opportunity for very serious mistakes.

The distribution system for a large irrigation project divides itself into several parts, which although closely interrelated, present certain individual aspects in connection with the location, construction, operation and maintenance of these unit parts. These different parts of an irrigation system will be considered under the heads of main and secondary canals, distributary ditches and the farm ditches used in irrigating individual holdings.

The managers of practically all large systems constructed in the last ten years have agreed as to the advisability of the policy of building the system complete to a delivery at the boundary of the individual holding or farm unit. The reasons for this are, first, the economy in cost and the engineering skill available for the location and construction work; second, the fact that a farmer starting in on a new place had enough to do during the first few years to prepare his land and build the farm ditches for irrigation. It may be pointed out just here, that one of the greatest sources of failure of new settlers on irrigation projects, is their inability or failure to suitably prepare the land and extend the distribution system without which

their efforts at irrigation lead to disappointment and fault finding, and very frequently, to an absolute failure.

The engineering problems connected with the location and construction of the main canals are many and varied, but are well understood by the men who have followed this line of work. The important matters of general policy affecting this part of the system concern alternative use of timber and concrete or masonry for the structures, the duty of water and the method of delivery, the source of water supply and land to be covered. In Canada, the lands to be irrigated, the water supply and the construction of works must all be investigated and approved by the Dominion Commissioner of Irrigation, which insures that fake irrigation companies do not discredit legitimate irrigation enterprise.

The distributary ditches carrying water to the individual farm units do not present any very large engineering problems, but they do require, for satisfactory results, a knowledge on the part of the locating and constructing engineers of the detailed and practical requirements of irrigation as carried out in the field by the farmer and an experience in operating and maintaining such ditches and the various structures that are a part of them.

The size of the distributary ditches should be determined not by the duty of water, but by the size of the head of water that it is desired to deliver to each water user, and the method by which such water is to be delivered. No matter how the water right is stated, the practical requirements of irrigation necessitate a delivery by rotation in sufficiently large heads to insure the rapid and economical irrigation of the land with a minimum waste of water. Such a system enables the crops to be irrigated at the proper time and increases the duty of water. It enables the farmer to cultivate as well as irrigate his land, which is of fundamental importance. On large holdings, the rotation may be carried out as between different parts of the farm, but with smaller holdings a compulsory rotation is most desirable. The distributary ditches should be designed and built to carry a flow of at least two cubic feet per second to each delivery. This allows a satisfactory irrigating head for flood irrigation, which system is considered to be the best

adapted for the majority of cases where the holdings are large, the slopes good and the crops consist largely of grain, hay and roots.

DISTRIBUTION OF WATER TO THE FARM.

The proper place for main laterals is on the divide or watershed if they can get there, or as near as possible if they cannot. The distributing laterals should follow the line of quickest descent, to avoid interfering with drainage. This latter is not always feasible owing to the rectangular system of land subdivisions in use in some countries, and a compromise must be arrived at whereby the laterals follow the survey lines as far as topography will permit. This compromise always results in some interference with drainage and almost always costs more in consequence. Another very important feature in the design of the distribution is the provision of a sufficient number of tail ditches. These are to carry surplus canal water into the natural drainage lines of the country and should not be confused with drainage ditches which are those built to assist the natural drainage lines in disposing of surplus irrigation water or precipitation. Tail ditches are an operating convenience, drainage ditches, an agricultural necessity. Under favorable, though unusual topographical conditions, it is possible to so arrange things as to combine the drainage ditches and the lateral system into one over a portion of their length. The system is not a good one, as it aggravates any tendency toward salting or alkali and sometimes results in silting up the natural drainage lines unless they have a very pronounced fall.

DISTRIBUTION ON THE FARM.

If the distribution outside the farm is the vital point in successful operation, the proper distribution on the farm is the most important factor in successful agriculture. No matter how regular nor how certain the water supply to the farm may be, it is worse than useless if not properly applied to the land. The farm ditches for the irrigation of the individual holding or farm units are of small interest from an engineering standpoint, but of the utmost importance in obtaining the final re-

sults for which the whole system has been built, namely, the increased production of crops on the land.

There are many methods of irrigating in use, the choice in individual cases resting on many factors, such as character of crop, soil, subsoil, slope, preparation of land, custom of irrigator, available labor and many others. No matter what method be used, the farmer must build on his own land a miniature system to distribute the water. Part of this system will be permanent and part only temporary, to be ploughed each year. Economical and proper use of the water is impossible unless the land is properly prepared to receive it, and it is just here that many irrigation projects have come to grief through lack of consideration of the problems of the water user, and not extending to the man on the land such advice and assistance as will enable him to advance on right lines. The greatest problem of all is to get the farmer to accept advice and go diligently to work to develop his farm on an up-to-date irrigation basis. The necessary preparation requires money or work, or both, and the tenderfoot is apt to underestimate its importance or else, through ignorance or indolence, postpone it to a later date, which frequently never arrives, for him at any rate.

In settling up large areas under new irrigation projects the majority of the people buying or taking up these lands are necessarily unfamiliar with the methods and appliances of irrigation. While farming by irrigation is the most scientific and satisfactory branch of the art, it gives proportionately less returns and more disappointment as a reward of careless and unskillful work than does farming without irrigation.

The first step in starting a new settler, is to convince him that his lands must be graded and smoothed for irrigation and that this is properly a capital charge against his land, just as the cost of such improvements as houses and barns. The land does not all have to be prepared at once, in fact it usually would take several years to prepare the entire farm, even though most of it was smooth enough to irrigate after a certain fashion from the first year. The heavy grading where the land is rough is usually done with a fresno scraper and in all cases should be finished with a leveller. This tool, or some modification of it, is used in every district where flood irrigation is the

rule, for a final smoothing of the land before seeding each crop. This smoothing should be a regular annual routine operation on the irrigated farms, as it smooths off all small irregularities, fills up the dead furrows and enables water to be spread evenly and rapidly. The preliminary grading has to be done but once, if done properly in the first instance. The leveller is usually made of plank, 16 to 20 feet long and from 5 to 8 feet wide with three or four cross planks to act against the earth, when the leveller is dragged across the field. The cross plank used as a cutter is, in the best type of leveller, arranged to be moved up and down with a lever, so as to control the depth of cutting.

Under most conditions, the head ditches constructed by the farmer will start at the turnout and be laid out to carry water along the side of the field and along the ridges to all high ground. Most of the head ditches may also be considered in the light of a permanent improvement as they are left in place and only require cleaning out or building up from year to year. Where flumes are required these must be kept in repair.

Most alfalfa, hay and grain crops will be irrigated by flood irrigation. This method requires field laterals about 100 feet apart, the distance varying with the slope, soil, crop, head of water used, smoothness of the land and skill of the irrigator. As a general rule there are too few ditches made and they are too small; the closer the ditches are together, the quicker the irrigation will be done and the more evenly the water will be applied. Water is turned from the field laterals on to the land at frequent intervals, by means of small dams of earth, or by movable dams of cloth, which are dragged down the ditch and set at each point where water is to be diverted. The irrigator must stay with and lead the water, planning ahead and using good judgment in his work.

For crops like potatoes, beets, or small fruits planted in rows, a system of furrow irrigation is preferable and in the course of time, a proportion of the field crops may be irrigated by this system. The furrows are carried from the head ditches down continuous slopes to the next ditch or valley and may be ordinarily from 330 to 660 feet long. Sometimes, pipes are used to regulate the amount of water running in each furrow.

CONSTRUCTION.

It is not sufficient for economical operation that a system be well designed. It must be well constructed. It is not meant by this that the highest standard shall be used, but merely that what is done shall be well done. It is a question which is the most difficult to operate cheaply, a well designed, badly constructed system, or the reverse. If anything it is the latter, for faults in construction can usually be remedied but faults in location are persistent and in many cases impossible to correct.

This should not excuse bad construction however. Bad construction is seldom cheap in the first cost and never economical. It is usually the result of too little attention to small details and to lack of proper supervision. Costly design may be easily almost nullified by cheap supervision. One very common cause of trouble is breaching banks. Sometimes this is attributed to omission in the specifications but it is generally due to non-observance of the provisions which are in them.

The methods and tools used in earthwork naturally vary much with local conditions. In North America, horse power and tools, except in the very largest canals, are well nigh universal. When manual labor is cheap, other methods would be used. The same applies to structures. A design or a material, or a method of construction suited to India would be out of place here (in Canada), and a design suited to a tropical climate would be altogether wrong in a northern climate, when frost is one of the principal agencies of destruction. Again too, construction by contract may be advisable under one set of circumstances, and the exact contrary in another. There is no doubt that there is great economy in building structures of a permanent type in the main carrying canals when the money available will permit of this policy. Such structures besides being more economical as to actual construction and maintenance through a series of years, also add to the reliability of the canals and this feature is a most important one in giving satisfactory service. The failure of a dam, headgate or drop, in a main canal at a critical time, may not only entail a considerable loss to the farmers individually and a large total loss, but does more than anything else to bring about dissatisfaction among the water users.

MAINTENANCE.

One very important factor and a frequent cause of trouble especially in cooperation schemes, is insufficient attention to maintenance and renewals. A structure shows signs of requiring attention, but for various reasons, such as lack of funds, or because it is no person's particular business, nothing is done. It fails in some part and is hastily patched up, finally it fails as a whole at a critical time and something approaching disaster may result. Proper attention at the right time would probably lengthen its life very considerably and would certainly avoid the disastrous results of a failure when such can least be afforded.

ENGINEERING.

Another very important prevalent cause of trouble, especially in cooperation schemes, is cheap engineering. This does not necessarily mean cheap men in charge. On the contrary it is not unusual to find expensive consulting engineers without sufficient funds to make the proper surveys when they are most needed. Almost invariably it will pay to spend a considerable sum on an accurate topographical survey of the whole area to be included in the project. There are very few projects where an accurate large scale topographical map would not save its cost many times over, but comparatively speaking, how few there are, where such a map is available on which to project and co-ordinate the whole system down to the last detail or even beyond. For instance, a settler needs aid or advice in preparing a difficult piece of land; with an accurate map available, a scheme can be worked out in the office and carried out on the field with little change; without it, a special survey must be made.

Again, it is not unusual to find the work as a whole in very competent hands, but for lack of funds the details are placed in charge of inexperienced men who have to acquire their knowledge at the expense of the constructing organization, with a resulting cost far in excess of what it need have been had the proper skilled assistance been available from the start.

MANAGEMENT.

Many projects suffer from petty economies in the management. It is an old saying that you cannot make an omelette without breaking an egg, and it is true. It is also true that a bad egg will spoil the omelette. A competent manager is worth an adequate salary and should get it, for he can save its cost many times over. It is hard to convince canal companies of this fact and as a result we find costly projects in the hands of cheap managers with the inevitable result of unnecessarily high operating charges. Large corporate- or government-managed projects do not suffer to the same extent from this cause as the small cooperation schemes, but even then it is not unknown. The necessary qualifications for a competent manager of course vary with the condition under which the project is operated. The successful manager, who has been accustomed to Indian or Egyptian conditions might fail utterly under conditions as they exist in North America.

So also the organization must differ. Some of the governing factors may be outlined as follows:

First, there is the extent to which the settlers are organized, or in other words, to what extent do they relieve the management of the whole or a part of the details of operation and maintenance?

Second, there is the size of the project. Evidently the organization of a project covering two or three hundred thousand acres must be more complex than one of two or three thousand.

Third, the type of the project. Distribution by open ditches must need a different organization from distribution by pipes, and pumping projects from purely gravity projects. Again, a project which is divided into units by well marked natural features differs from a project confined to one valley with one long straight-away canal. Character of construction also enters, as on it depends that which requires most supervision, operation or maintenance.

Another and very important factor is the character of the settler. By this is meant his race or nationality, the system of government to which he is accustomed, his habits and customs. The laws of the country are important, so also is the respect

in which laws are held, considered as a national or racial characteristic.

The above conditions affect the scheme of organization in very different ways. Many of them are self-evident or have been touched on in passing. Of them all, it is probable that the character of the settler has as much effect as any. In the first place, has the prospective settler had any experience in irrigation? In this country, probably not. Well then, he must be taught, and competent teachers must be a part of the organization. Or perhaps he has had experience in another country where things are different, and has not enough originality to adapt himself to new conditions. He also must be taught, but the same kind of teacher will not do, always. Again, a number of settlers may immigrate and settle in a body, coming from some older community. These men will probably bring with them some form of organization or perhaps only the germ of one, but they require very different handling from the other two classes. Moreover it must be remembered that the kind of organization which is necessary does not depend on the extremes at either end, but on the average level in such characteristics as industry, education, intelligence, conservatism, and ambition.

DEMONSTRATIONS.

On all but projects in old and settled countries, something in the way of demonstrations and object lessons is necessary and even in the exception, seldom does anything but good. Such farms must be carried on under conditions exactly parallel to those the settler has to face or they defeat their own ends. Moreover they must pay, or they are not object lessons.

OWNERSHIP OF PROJECT.

The ownership or title in the project is handled in many ways. It may be private, corporate, government, or cooperative or it may be of a mixed character. In some cases it is vested in corporate or government hands until settled entirely, or to a fixed proportion when it passes into the hands of the settlers and becomes cooperative, or the control of the corporation may pass into the hands of the settlers in a similar way. In others, the title is vested in the corporation or government

in perpetuity but the settlers are given a voice in the management, subject to certain fixed rules. These transfers are best carried out by the organization among the settlers of water users associations, which assume certain obligations in return for certain considerations.

WATER USERS' ASSOCIATION.

These associations may become the owners of the project or they may simply undertake the operation either in whole or in part, depending largely on the size of the project. For small projects it is probably better to let the association assume the whole responsibility, ownership included. Larger projects which must be divided into districts, for convenience, are probably better handled when the ownership and the operation are separated, letting the associations do the distributing while the owner does the carrying, but keeping the title to the whole in the hands of the owner.

Districts.

In order to be workable, the districts must be somewhat restricted in size. Unless there is a community of ideas and interests, the associations are liable to waste time and money in fighting over non-essentials and this is more likely to occur in very large or very small districts. They should not be large enough for local politics to develop and they should not be so small that petty jealousies can influence their success.

Organization of Associations.

As a general rule, the associations should be organized as corporations under charter and by-laws with proper officers and powers of assessment and to engage the necessary employes. Their charter should provide the means whereby the funds necessary to carry on their work are to be raised and also for their collection. Such associations have advantages altogether apart from their primary object. Most of these will suggest themselves but the following are among the more important: they encourage general district improvement, progress in education, social betterment, cooperation in buying and selling of seed, crops and farm machinery, and in many other ways they assist in developing independence, reliance, mutual respect and assistance, and so forth.

CONCLUSION: THE HUMAN ELEMENT.

In conclusion, it cannot be too strongly stated that when a project fails to do what it was intended to do, in nine cases out of ten the cause is to be sought in the human element of the problem. Other causes may have helped, such as high cost of water right, poor construction and sometimes actual fraud, but generally these could be overcome. Lack of consideration of the human element spells failure, unaided. It is proper therefore to say that quite as important as any improvement in distribution systems or in methods or in appliances, is the man for whom they are provided and that he requires study quite as much as or more than they do. It is a fundamental fact that it is the water user who finally determines the success or failure of the project and that it is his willingness to adapt himself to the methods and appliances of irrigation farming which determines his success and, consequently, the success of the irrigation enterprise. Irrigation managers are everywhere realizing this condition and are studying stock raising, dairying and crop rotation as they should be worked out on an irrigated farm, quite as much as the details of water delivery and the various problems of operation and maintenance.

DISCUSSION

Mr. Drake.

Mr. E. F. Drake* (verbally) stated that he agrees with the views expressed by the authors. There have been failures in some of the Canadian projects which are explained in the paper. One of the greatest difficulties in handling new irrigation projects is to secure experienced irrigators. The most successful farmers on any successful irrigation project are not looking for lands in other projects; so that the newer projects are forced to take less desirable classes of farmers who may not have succeeded in their original locations. Many projects have sold much land on a speculative basis, the purchasers expecting to secure very large profits from the sale of the land itself and having little intention actually to farm the lands that were purchased. This condition is particularly true on projects where moderate success can be attained with dry farming. In some cases, although twice as high a price may have been paid for land under irrigation systems as would have had to be paid for similar lands under dry-farming conditions, many of the settlers make use of the land only by dry-farming methods, and thus secure no benefit from the existing irrigation system. This practice ties up additional capital in the land without corresponding benefit. Other

* Of the Department of the Interior, Ottawa, Canada.

cases are the purchasing of relatively large irrigated areas and actually irrigating only a small portion of the land for several years. In such cases the small area irrigated has to bear the burden of the investment for the full acreage owned. Such conditions lead to dissatisfaction; and generally the operating company is blamed for all such troubles, although usually it is not responsible. Mr. Drake.

The remedy for such poor conditions is not apparent; but it is desirable in settling large projects that they be opened by units, the lands nearest the head of the system being opened first for settlement and later units not being opened until the first units are settled completely. Such a practice would save not only operation and maintenance costs but also would postpone the construction costs on the units until they are needed for use. It has the further advantage to the constructing company, that if the first units developed and sold prove to be successful, later units generally can be marketed for higher prices.

Mr. Gavin N. Houston,† M. Am. Soc. C. E., Mem. Can. Soc. C. E. (verbally), stated that the difficulty in settling up large projects often is greater in localities where irrigation is not an absolute necessity. If no crops can be raised without irrigation, the settlers have to make use of the water and the irrigation system, and the development usually is more rapid. If it is possible to secure some returns by dry-farming methods only, the increase of the area under irrigation generally is much slower. This tendency has been quite noticeable on some of the Canadian projects. Mr. Houston.

Mr. Elwood Mead,* M. Am. Soc. C. E. (verbally), stated that it is evident the paper deals with localities where there is considerable rainfall; and the advice given in it probably is good for such sections. In more arid regions, it would not be desirable to postpone preparing the land for irrigation. The best practice in arid regions is to get as much land as possible into irrigated crops the first year. Every year's delay means a loss of opportunity and a waste of resources. Mr. Mead.

Mr. F. H. Newell,‡ M. Am. Soc. C. E. (by letter), stated that the most striking part of the paper is summarized under the head of "The Human Element". It is beginning to be appreciated as never before that the success of any irrigation enterprise lies in the character, education and skill of the men who use the water, more than in the irrigation works themselves. Not long ago, when most of the larger irrigation systems were being projected, it was believed generally and asserted confidently that it was necessary only to build the reservoir and main canals of a project, and then let the settlers do the rest. It was assumed that competent farmers would be attracted to the irrigable lands; and that (like the pioneers in irrigation development) they would unite in their own ways, adapt themselves to the conditions existing, build the needed distribution systems, initiate Mr. Newell.

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* Prof. Rural Institutions, University of California, Berkeley, Calif.

‡ Prof. of Civil Eng., Univ. of Illinois, Urbana, Ill. Until recently, Director, U. S. Reclamation Service, Washington, D. C.

Mr. Newell. methods of irrigation, and advance rapidly toward success in raising and marketing crops. It was recognized that cooperation and concerted work must be undertaken; but it was believed that these matters could be left to the characteristic western spirit, which relies upon individual ability and enterprise overcoming all natural obstacles.

This belief is now known to have been a mistaken one, and the results have been largely disastrous. Great irrigation systems have been built, but a large part of the land which might be irrigated from them remains unutilized, because the early settlers on the lands did not make such financial successes as to attract additional settlers. In short, they did not find that irrigation pays, or at least that it pays sufficiently well for them to urge their relatives and friends to do as they did.

The reasons for the delay in settling irrigation problems have been many, but the one fundamental cause of slow irrigation development is that pointed out by the authors—a neglect in the past of the human element.

Now irrigation works can be extended only because of demonstrated successes under the irrigation systems already built; and such demonstrations can be made only when the lands already provided with irrigation are being tilled profitably. Such profitable tilling can be done only by men and their families who have been selected for their fitness with greater care than has been exercised in the past.

With unbounded faith in the ability of the individual to overcome difficulties, the men in responsible charge of irrigation works and of newly irrigated land have advertised broadcast and have endeavored to attract anyone as a settler, with little or no regard to his ability, age, energy or experience. The sole qualification required in the newcomer was to be able to make a first payment on the land, even though this took his last dollar. The results have been deplorable; and it is seen now that irrigation as a whole would be further advanced had the men in responsible charge refused permission to many of the present settlers to go upon the land. The most careful thought and effort in connection with the works should have been devoted to selecting and securing the families well adapted to the new enterprise, and even though very few settlers were obtained thus, yet those few undoubtedly would have advanced the work of settlement more rapidly than the many who were permitted to try their luck.

It has not been understood well that there is a marked difference between irrigation development and investments in manufacturing enterprises. If a corporation builds a great factory, costing millions of dollars, it can take into the works almost any man who applies, and by the somewhat crude but moderately effective process of ''hiring and firing'' finally secure by elimination an effective body of workmen.

With irrigation systems costing perhaps an equal amount, the men who actually do the work on the land are in an entirely different relationship to the enterprise. In a sense they are partners, and they cannot be ''fired'' when their incompetency begins to appear. On the contrary, neces-

sarily they must have acquired some form of title to the land and usually to the works. They have made a considerable investment of time and money in establishing a home; and public opinion would not tolerate abrupt changes or removals from the land and the substitution of a better man, even though its desirability might be evident. The mediocre or unsuccessful must remain, often a detriment to the community, until of his own initiative he moves to some other locality. In the meantime, the interest and the maintenance charges have been piling up, and although theoretically those and other debts may be collected ultimately from the unfortunate farmer, practically this can be or should be done but rarely; and he should be permitted to depart in peace with such of his household goods and other property as he can remove. Mr. Newell.

Everything considered, the results up to the present time point to the necessity of getting more and better settlers on irrigated lands, even at the risk of long delay and of incurring considerable expense; and it is beginning to be appreciated that competent settlers are rare. There is much glib talk about bringing over farmers from Belgium or other distressed agricultural regions; but as a matter of fact the real farmer and his family are appreciated and needed even up to the edge of the War Zone and he is not inclined to leave nor do the authorities wish him to do so. The kind of man who can be induced to go to a new country often is the restless fellow who has not made a success in anything, and who will be as easily discouraged and attracted away from his new location as he was from his old.

No royal road has been discovered yet to the winning of real agricultural settlers; and it is one of the most difficult of undertakings. While the need of obtaining such settlers is now understood, and larger expenditures in getting them can be justified now than in the past, apparently not much progress has been made in effective methods of obtaining the needed families. The word "family" is used advisedly, as on a farm a single man is of little use. The permanent success of any irrigation project is due to the united efforts of well-balanced families—the man, the wife and the children, each doing his or her proper share and all working together not only for the development of the farm but also for the better family and community life which is the foundation of successful agriculture.

Paper No. 37

THE UTILIZATION OF GROUNDWATERS BY PUMPING FOR IRRIGATION.

By

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INTRODUCTION.

The purpose of the following paper is to present in brief compass a survey of modern irrigation pumping and a retrospect of the progress of the past ten years. The paper treats briefly of groundwater supplies, their occurrence, regimen, and recharge; of the methods of developing groundwater supplies by means of wells; of pumping machinery; and of the economics of this type of irrigation. It is a discussion of what is, and not of what ought to be; and a mention of new things rather than a description of the old.

Pumping for irrigation in a crude form is of great antiquity. In Egypt, India and China odd pumps, such as endless chain buckets and scoop wheels, were employed; and the Kairez or long tunnels of central Asia, many of which are still in use, were remarkable examples of groundwater development suited to earlier times. But probably at no time in the past has there been any utilization of groundwaters at all comparable in extent or in effectiveness with that of today in the great Southwest, from Arkansas to California. And, with the advancement in knowledge, in methods, and in machinery, pump irrigation has come to occupy a distinct and important field of engineering activity.

The magnitude of pump irrigation was revealed by the census of 1910.[1] * The statistics relating to irrigation show a total of 307,496 acres (124,400 hectares) irrigated by pumping

* [1] is reference to bibliography number.

from wells in 1909 in the United States west of the 100th meridian. Ninety percent of this acreage was in California, and the remaining ten percent was situated mostly in Arizona, New Mexico, Texas and Washington. Also, the census furnishes data on the irrigation wells in use in 1910. The total number of pumped wells was 14,558, of which 10,724 were in California. The total capacity of the pumped wells was 5,426,139 gallons (20, 540 cu. m.) per minute, of which amount 76 percent was in California, while Arizona, New Mexico and Texas were of next importance in the order named. The census of 1900 did not include any data on wells or irrigation pumping.

Pumping from wells for the irrigation of rice, in Louisiana, Arkansas and Texas, is of increasing importance, having been developed entirely since 1900. The number of pumped wells in the rice district in 1910 was 848, with a combined capacity of 802,653 gallons (3038 cu. m.) per minute. Texas was credited with 55.5 percent of the total well capacity, Arkansas with 33.5 percent and Louisiana with 11 percent.

Since 1910 there has been a rapid increase in irrigation pumping. Representatives of the office of Irrigation Investigations, U. S. Department of Agriculture, have made a canvass to ascertain the number of new pumping plants installed in California during the years 1911-1914 inclusive. Their estimate is 15,262, which is 164 percent of the number in use in 1910. Allowing for a moderate number of replacements, it is certain that the number of plants has more than doubled in four years. In Arizona, the percentage of increase is much higher. It is believed that there are four times as many pumping plants in operation now as in 1910. The preparation and cropping of land has lagged somewhat behind the water development, however, and the acreage irrigated at the present time in Arizona is probably not over one-half of the acreage to which the pumping plants are ready to supply water.

Elsewhere in irrigated countries, it is presumable that much progress is being made along similar lines. It is hoped that this paper will be amplified by discussions that will record the recent progress in those countries and, also, the present practice in other regions than Arizona and California, to which this paper chiefly applies.

From the nature of pump irrigation it is of necessity divided into small projects. Many times, indeed, the projects seem quite insignificant, perhaps a pump capacity of 300 gallons (1.14 cu. m.) per minute and 40 acres (16.2 hectares) of ground. It is only when the hundreds of projects are considered in the aggregate that their importance is truly appreciated. But, it must

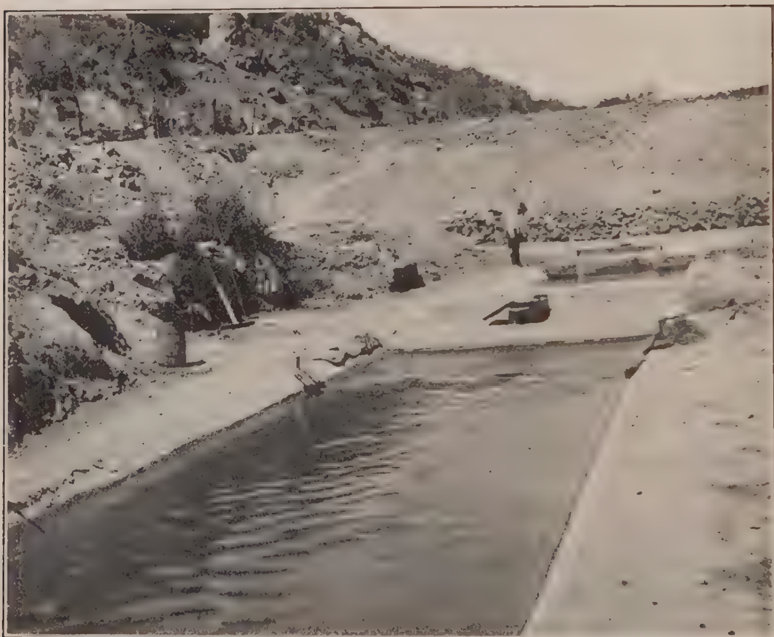

Fig. 1. Intake to New Siphon of Tucson Farms Co. Ditch.

A Venturi irrigation meter is being checked against a temporary weir. This ditch carries the combined flow from 20 wells.

be remembered that unless the small individual project is scientifically designed and intelligently operated, failure or a low degree of success will result. Pump irrigation stands or falls with the farmer's individual pumping plant.

Occasionally large groups of pumping plants are designed as a single unit by one engineer. Such are the Portales Valley project in New Mexico,[2] the Tucson Farms Co. project at Tucson, Arizona, and the Sacaton pumping project of the U. S. Indian

Service.[3] The first named included 69 pumping plants at the outset, the Tucson project has 78 pumping plants, while the Sacaton string of ten wells has a capacity of serving 10,000 acres (4047 hectares) of land in one unit.

There are many large irrigation pumping projects in central California, Oregon and Washington, which derive their water supply from flowing rivers. These projects are noteworthy on account of the high character of pumping machinery used. Yet they do not depend upon groundwater supplies and hence they are outside the province of this paper.

In general the individual plants are operated independently of each other. For various reasons, cooperative pumping is disliked and evaded, but, as will appear later on, there are obvious advantages in cooperation, even for small plants.

GROUNDWATER SUPPLIES.

In times past, groundwaters have been very much of a mystery to most people, and even now in many localities one hears the most astounding theories concerning their magnitude, motions, origin, and the methods of locating good supplies. Today, however, there is available to the engineer a comprehensive and valuable mass of data on the groundwaters of this country. For these data we are indebted, in large measure, to the able scientists of the U. S. Geological Survey, whose researches have been extended into every State. The results of their studies have been embodied, for the most part, in the familiar red-covered "Water Supply and Irrigation Papers". It is of interest to note that the first paper in that series, published in 1896, was one entitled "Pumping Water for Irrigation". Since 1903, there has been a Groundwater Division of the Geological Survey, under the direction, at first, of N. H. Darton, later of W. C. Mendenhall, and since 1912, of O. E. Meinzer, to all of whom great credit is due for the valuable results accomplished. A most useful work which is greatly needed now is a volume bringing together for the general student all the important principles relating to groundwaters and correlating the salient facts that are now to be found in the many scores of detached reports.

Perhaps the most notable quantitative study of ground-

waters so far published is that of Chas. H. Lee, Assoc. M. Am. Soc. C. E., in Owens Valley, California.[4] The success attained in Lee's investigations emphasizes strongly the possibility of basing important future groundwater development upon a foundation as rational and as reliable as that commonly enjoyed by surface water projects.

Groundwater occurs widely distributed thru all classes of material from sand to granite. Altho various rocks, especially sandstone and limestone, are drawn upon largely for water supplies in other regions, they are of little importance in the Southwest where pump irrigation is practiced. The great structural valleys of the Western States and the coastal plains of both California[5] and Texas are filled to great depths with loose unconsolidated materials, colluvial and alluvial, which serve as groundwater reservoirs. Practically all of the water pumped for irrigation is derived from such sources of supply. Cross-sections of typical valleys, as revealed by logs of wells, show alternating strata of gravels, sands, and clays, with coarse unsorted outwash on the flanks and much calcareous cementation in the deeper gravels. The water-table conforms in some measure to the surface topography, but normally it has much flatter gradients.

In Arizona valleys, the Recent gravels are in most cases coarse, loose, and clean. The underlying Pleistocene formations,[6] deposited under more arid conditions than those of today, are less sorted and porous; alternating with the alluvial or lacustrine clays, are beds of gravel and outwash, oftentimes tightly cemented with a lime matrix; former persistent land surfaces are marked now by layers of travertine, known locally as caliche; and deep wells show an increasing induration, so that the valley fill merges by insensible gradations into solid rock. Consequent upon these conditions are two important results: First, the underdrainage of valleys is restricted and the water-table is maintained within economic reach of the surface; and second, the first water-bearing gravels are the best ones, so that deep drilling is seldom justifiable or necessary. In southern California, too, it is most expedient, oftentimes, to locate wells in the Recent gravels close to the river courses and to force the water thru long pipe-lines to the land to be irrigated.

It is now recognized that, with some exceptions, the rock basins of the structural valleys of the Southwest are practically water-tight, and that, therefore, each valley fill is an entity in its relation to groundwater. The contained groundwater can be compared with the water held in a surface reservoir, but with this distinction, that as the draft on the groundwater reservoir increases, the pumping lift increases, and finally pumping operations arrive at economic limitations. As in the storage of surface waters, groundwater supplies must be renewed, and they are by no means inexhaustible. In localities where pump irrigation is highly developed already, the great problem is the management of the groundwater supplies so as to secure maximum use of the groundwater reservoirs without serious permanent lowering of the water plane.

The valley fill receives increments to its water supply from various sources, chief of which, in the Southwestern States, is percolation from the streams which issue from the mountains. Seepage from irrigation canals and the downward percolation from irrigated lands are of next importance,—an unflattering commentary on our present systems of irrigation. Direct precipitation on valley lands has little influence on the supply, and, likewise, the overflow areas of valley bottomlands, for while they absorb considerable water, yet a surprisingly small amount of it reaches the saturated groundwater zone. Those five items constitute the water income of a groundwater reservoir; the outgo consists of the water pumped or flowing from wells, and the natural water losses. The latter consist of drainage into rivers, underflow thru the deposits overlying the outlet gap of the rock basin, springs, evaporation from the soil and transpiration from vegetation. The heaviest losses, evaporation and transpiration, are restricted to shallow-water areas. The water can be lifted from 7 to 10 feet (2.1 to 3 m.) by capillarity in fine soils, but, usually, transpiration from the stems and leaves of vegetation accounts for the major part of the groundwater loss. In Owens Valley the loss was found to be mostly thru salt grass, while under different climatic conditions it takes place thru sage brush or other shrubs or thru trees.

The possible safe yield of a groundwater reservoir available for pumping includes all that portion of the natural losses

which can be prevented by lowering the water-table. Pumping at a few points is inadequate; wells must be located systematically at suitable intervals on the shallow-water area or on the flanking slopes where they will intercept the groundwater movement. Estimates of safe yield are based, usually, on investigations of rainfall, stream-flow, and seepage losses from streams. The method of estimating safe yield by measuring the natural water losses is likely to be used more as our knowledge of plant transpiration increases. Lee measured both income and outgo in Owens Valley and found an equality between them. Sometimes it is desirable to base estimates on rainfall records, areas, and the logs and yields of wells, but such estimates must be regarded as of a reconnaissance nature.

In the more arid valleys, the entire discharge of mountain streams is absorbed into the delta cones built up at the canyon mouths or into the gravels along the upper stream courses. But, where, normally, a portion of the river discharge escapes to the sea, or at least beyond the irrigated area, it is possible to increase the groundwater supply by artificially spreading out the floods over gravelly areas into which the flood-waters are absorbed. Water-spreading, as it is called, has become an established feature of river control in southern California.[7] It was first attempted on the Santa Ana River, at San Bernardino, about 1900, and was continued on a small scale by private companies until 1909. In that year a public organization, involving all the irrigation interests of the Santa Ana River, was effected, spreading ground has been acquired, and the magnitude of spreading operations gradually extended. Water-spreading is practiced also on the San Jacinto and San Gabriel rivers, and on many smaller streams. The method used on the Santa Ana River is to build concrete head-gates at favorable points, to divert the water into canals or old channels and conduct it to broad sand and gravel areas, to divide the stream into laterals and subdivide each lateral into smaller ditches, and, finally, to discharge the water broadcast over the spreading ground. Varied methods are used on other rivers to meet local conditions. On the San Jacinto River, where the surface is a uniform slope of sand with a grade about one-fourth as steep as that on the Santa Ana River, the basin method is used. Areas of several acres each are enclosed with levees.

The water is diverted from the river into the highest basins and overflows successively into the lower ones. Water-spreading is of the highest value and can be made to equalize the water supply between wet and dry years. There are many places in Arizona, and no doubt in other states and other countries, where spreading is needed and is practicable.

The amount of groundwater that can be developed at one place is extremely variable. The geologic criteria for good wells are: clean coarse gravels, and ample continuous supply of water. The former factor is dependent on the character of rocks in the mountains of the watershed.[8] Granitic rocks invariably produce coarse sands and gravels, while soft, close-textured rhyolites produce thick beds of clay. The contrast is seen frequently on the opposite sides of a valley. Examples of heavy yields from wells are quite common. The battery of ten wells of the Tempe Canal Co., at Tempe, Arizona, yields 27 second-feet (0.765 cu. m. per sec.) with 14 feet (4.3 m.) draw-down. These wells are spaced at 50-foot (15.2 m.) intervals and are 200 feet (61 m.) in depth. The average yield of eighteen 16-inch (40.6 cm.) wells near Mesa, Arizona, drilled by the U. S. Reclamation Service, is 0.32 second-foot per foot (0.03 cu. m. per sec. per meter) of draw-down. The Azusa Irrigating Co., in the San Gabriel Valley, California, has a 26-inch (66 cm.) well, 400 feet (122 m.) deep, which is said to deliver 9 second-feet (0.255 cu. m. per sec.). The lift at this well is 160 feet (49 m.). The Covina Irrigating Co., has a 26-inch (66 cm.) well, of the same depth, which delivers 7.2 second-feet (0.204 cu. m. per sec.).

The quality of irrigating water is a matter of critical interest to engineers, and not a few wells have been abandoned because the salty character of the water unfits it for irrigation. A costly well near Sentinel, Arizona, was found to contain 575 parts of sodium chloride per 100,000. It was pumped continuously for several weeks at the rate of about 1100 gallons (4164 litres) a minute in the hope of exhausting the brine and obtaining better water, but there was no material improvement. In some localities the first water-bearing stratum yields very alkaline water and the deeper strata yield good water; in other places these conditions are just reversed. Specifications for some recent wells have required separate samples of the water from each

stratum for the purpose of analysis. Black alkaline waters can be improved by treatment with gypsum. In the Rillito and Whitewater valleys of southern Arizona the well waters contain sodium bicarbonate, and in both valleys there are beds of crude gypsum close at hand. Water treatment plants for irrigation water supplies are an attractive possibility.

WELL DRILLING.

Irrigation wells are of the following types:

1. Wells dug to full depth
2. Wells drilled or bored from the surface
3. Wells dug to water-level, and drilled or bored below the water-level.

The first type is decreasing in use. It is best adapted to valleys where the water-plane is shallow and the first water-bearing stratum is the best one, conditions that are found frequently on the bottomlands of Southwestern rivers. Well digging is a simple operation above the water-plane, but is neither simple nor easy below the water-plane, especially in caving ground. The difficulty lies in the control of the curbing. Timbering, similar to that done in mine shafts, has been used. But the best results have been obtained with caisson curbs built of reinforced concrete. These curbs are built above the water-plane; the concrete is allowed to cure for a couple weeks; and the curb is then sunk by excavating thru the interior, usually with shovels and buckets, but in one instance with a dredge and orange-peel bucket. As the caisson is lowered, new rings of concrete are added at the top. The reinforced concrete has greater strength and integrity than the brick and masonry walls used previously. An important advantage of caisson curbs is that the equipment required is not elaborate, and many farmers have been entirely successful in sinking caisson curbs without employing skilled help. So far as known, the first reinforced-concrete caisson wells were sunk about 1906. In 1913, a well was sunk by the U. S. Indian Service near Banning, California, by means of a shield, on the principle used in driving tunnels beneath rivers. The well reached a depth of 100 feet (30.5 m.) below the water-table, an achievement of note for a dug well.

The second type of well, drilled or bored from the surface, has steadily increased in favor during the past decade. The method most commonly employed for these wells is the drop-drill method or its modification, in which a mud-scow, that is, a heavy sand bailer with a circular cutting edge, replaces the ordinary drill bit and stem.[9] In California and in Arizona the

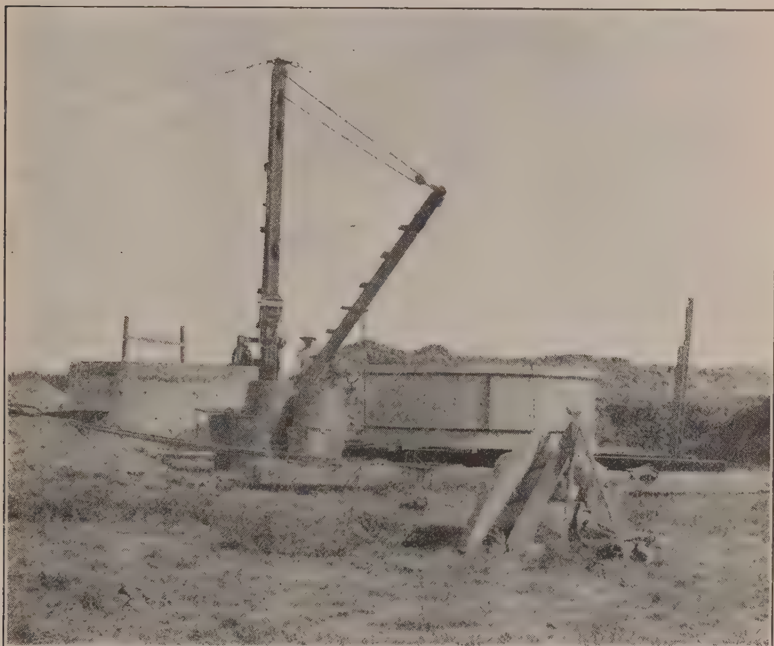

Fig. 2. Inside and Outside Forms for Reinforced Concrete Caisson Well Curb.

The pit has been excavated to water level and the outside forms are shown ready to be lowered. This type is recommended where the water-table is at shallow depth and the first water-bearing stratum furnishes the largest and main supply.

typical irrigation well is a 12-, 14-, or 16-inch (30.5-, 35.6- or 40.6-cm.) cased well, drilled to a depth of from 150 to 300 feet (45.7 to 91.4 m.). Portable rigs are used almost exclusively, and "stove-pipe" casing is preferred because of its smooth exterior and its low cost.

Another method, however, is threatening to supplant the familiar drop drill. The new method is the modern hydraulic

rotary—not the process formerly employed, wherein the well casing with a toothed cutting shoe was rotated, but a new process, which omits the casing and uses a line of heavy drill rods to rotate a fish tail bit. Instead of clear water, the fluid used is clay

Fig 3 A California Mud-scow, Driving Collar and Jars for Sinking 16-inch Wells.
The circular shoe serves to cut the formation in place of the ordinary drill bit. Good samples of the formation are obtained.

mud, the consistency and specific gravity of which are maintained or changed according to the formations encountered. The walls of the hole are sealed with mud and are thus kept intact. Even coarse, running gravel can be held by using heavy mud, and

frequently the mud is thickened until its specific gravity reaches 1.1. By means of a duplex reciprocating slush pump, the fluid is forced down thru the rods to the drill. It then returns upward, outside the rods, bringing the drillings with it. On reaching the surface it is led thru a circuitous ditch, in which the drillings settle out, to a small sump, from which it is pumped again into the well. When the final depth is reached, the drill rods are withdrawn and screw-joint well casing is set in the hole. The log of the well being known, a well screen—either wrapped, or shutter, or plain perforated—can be placed in the column so as to set opposite the water-bearing strata, or well casing can be used for the whole column and then perforated. Finally the well must be "developed" with clear water to bring out all the mud and open up the sand and gravel strata.

This latest rotary method originated about 1890 in Louisiana, where it was used in an obscure way. But when the first gusher of the Spindle Top oil district was obtained in 1901 by the use of this method, immediately the method sprang into notice everywhere. It came into general use in the rice and oil districts of Texas very quickly, and remarkable records of fast drilling in Texas sands have been reported. In 1906 rotary rigs were introduced into the California oil fields, and on account of the greater depths of wells, the rigs were built much heavier than those previously used. About 1910 it was adopted extensively in northwest Texas for water wells, and since then has been tried out in many locations in New Mexico, Arizona, and southern California. It has demonstrated its applicability under the conditions of our Western valleys, despite the greater difficulties to be met in gravelly formations. In the oil fields of California it has replaced cable drilling to a considerable extent; but drilling for water is still done largely by the old system, especially where the formations are known to contain boulders. The relative cost of drilling deep oil wells in California by the two methods, rotary and drop drill, is still a subject of debate; but for wells of less than 400 feet (122 m.) depth in boulder formations, the unit cost by the standard method is unquestionably less than by the new hydraulic rotary method.

However, it is claimed that sufficiently larger supplies can be obtained from the same formations to justify the extra cost,

and much evidence has been adduced to sustain this claim. The author knows of three localities where only wells of less than 500 gallons (1893 litres) a minute had been drilled prior to the coming of a rotary rig, but with the rotary, yields of from 1200 to 2000 gallons (4543 to 7570 litres) a minute have been developed from shallow wells, in each of the three districts.

The State of Arizona has appropriated funds for deep wells in four counties, the avowed purpose being to determine whether or not there are artesian waters in those counties. One of the wells has been completed. It is in the Sulphur Spring Valley, in Cochise County. Generalized specifications were prepared and bids were called for on the basis of depth, since the fund, $7500, was a fixed amount. A rotary driller guaranteed 1500 feet (457 m.) depth and received the contract. The drillers with drop-drill rigs bid on various depths from 900 to 1200 feet (274 to 366 m.).

The well was sunk rapidly to 1135 feet (346 m.), at which depth semi-indurated and cemented gravels were encountered. The ordinary fish-tail bit was quite inadequate; freshly sharpened bits became blunt in three hours' time. Much time was lost, also, in removing and setting in the long string of drill rods. The situation was saved by the purchase of a rotary rock-drill bit, the invention of H. R. Hughes, of Houston, Texas.[10] It consists of two cone-shaped hardened-steel cutters, carried on the arms of a heavy stem and rotating at right angles to each other. The cutters run on bronze bearings and are lubricated, with the heaviest possible lubricating oil, from a small storage pipe inside the drill rod. With this bit, 3 feet an hour could be made, and the contract depth of 1500 feet (457 m.) was soon reached. The rock-drill bit will have much influence in extending the range of usefulness of the rotary process.

The perforation of well casing and the "developing in" of the well after perforation have been much neglected in the past. Many cases are known in which wells supposed to have been perforated have been found to be almost water-tight; the perforator knives frequently dent the casing instead of cutting it; and well contracts have called for little or no "development" after the perforations were made. Rotary drilling, however, requires that the mud forced into the walls of the drill hole must be removed.

Great ingenuity has been displayed in the various processes of washing, jetting, churning, and pumping, with water and with compressed air, by means of which the water-bearing strata are

Fig. 4. A Stack of 4-inch Drill Rods and a Single-cut Perforator used at the State Artesian Well at Servoss, Arizona. The Perforator Was Made by the Driller at the Site of the Well.

opened up, not only close to the hole but for a considerable distance back from the casing. It has been possible sometimes to remove from the hole an amount of sand equal in volume to four or five times the volume of the hole. One of the most effective

methods is "rawhiding" the well. This consists of alternately starting and stopping a centrifugal pump, the bowl or bowls of which are set 30 to 60 feet (9.1 to 18.3 m.) below the groundwater level. There should be neither foot valve nor check valve,

Fig. 5. The Mackey Four-way Casing Perforator, Showing the Four Roller Knives and the Grooved Knife-frame Removed from the Main Shell.

for it is essential that when the pump stops, the column of water should return suddenly into the well. In the author's opinion, the superior yields obtained by rotary drilling are due, not to the method of drilling but to the ingenious and long-continued

processes of "developing", processes which drillers with cable rigs can learn and are learning, to use with equal effectiveness.

Another accomplishment of the rotary method is the reaming out of the upper portion of the hole to 26 or 30 inches (66 or 76 cm.) diameter, so that turbine pumps of large size can be lowered to position sufficiently deep below the water-plane to give a heavy draw-down. The 26-inch (66 cm.) casing and 24-inch (61 cm.) pump bowl have become very common during the last five years.

The third type of well, dug to water level and drilled below water level, is still preferred in many localities. This type permits the installation of large-bowled centrifugal pumps, horizontal or vertical, and it is undeniable that until within two years such pumps were giving much better efficiencies than were obtainable from pitless turbine pumps. Wells of this character are now favored where the fluctuations of the water-table are slight, where the draw-down during pumping is moderate, and where electric power is available for direct-connected units. A fine well of this type, with concrete-lined pit, has just been completed at the University of Arizona. Any kind of pump whatsoever can be installed in this well for testing purposes, and it is hoped, thereby, to contribute materially to our common knowledge of the action and the merits of the many types of pumps now in use or proposed.

Newell and Murphy[11] consider that a caisson curb sunk as far as practicable below the water-table, with two or more drilled feeder wells in the bottom, is the most desirable form of construction. Wells of this type are common in Arizona.

Miscellaneous other well types are found in various localities according to local conditions. As an illustration, there are in the neighborhood of Willcox, Arizona, numerous wells consisting of an unlined pump pit to near water-level and an uncased hand-auger hole thru the clay to the first water gravel. These wells yield from 300 to 700 gallons (1136 to 2650 litres) per minute, and their cost is insignificant. Machine augers, also, are used in a few localities, with indifferent success.

The attention of engineers should be directed to the necessity of assisting well drillers to report the logs of wells correctly. Three instances have come to the author's attention recently, in

each of which the log was wrongly reported. In this connection, the California mud-scow method provides the surest means of ascertaining the character of the formations, for chunks of the materials in their original condition are almost sure to be brought up in the bailer.

PUMPING MACHINERY.

Economically, pump irrigation is dependent in large measure upon the machinery used. Altho this fact has been realized, yet there has been a lack of appreciation of the benefit to be derived from engineering design and supervision of the individual pumping plant. Usually the buyer is a farmer with little or no familiarity with pumping machinery, and he could well afford to expend 5 percent of the cost of his plant for engineering advice. Ordinarily, however, plants costing less than $10,000 are designed by salesmen, and salesmen, of course, have other interests to serve besides that of the prospective purchaser. The author has seen many instances of stranded farmers whose sad failures were due to the unwise selection of pumps or engines. One man of this class remarked recently, "I bought talk". Herein is a promising field of usefulness for engineers. In every pump irrigation district there should be consulting engineers prepared to write specifications and contracts and to supervise the purchase and installation of pumping machinery, and also to have similar charge of the development of wells. At the present time, contracts are drawn in optimistic vein by the salesmen and the liberal efficiency guarantees are so worded that the farmer cannot check them up.

In the design of farm pumping plants, it should be recognized as a principle that reliability and simplicity are of equal, if not greater, importance than efficiency and fuel economy. A power plant on a farm is at a disadvantage, often it is from ten to fifty miles from a machine shop where lathe work can be done, and the farmer himself is not a mechanic. Plants of less than 30 horsepower should operate without attendance for several hours at a time, and a breakdown at a critical time, when the crops need water, is likely to prove fatal financially.

Pumping machinery will be discussed under the three heads: pumps, oil engines, and electric power.

PUMPS.

The pump that is preeminently adapted to irrigation use is the centrifugal pump. Probably 80 percent of the irrigation water lifted from wells is delivered by centrifugal pumps. The advancement in recent years in the design of pumps of this class has been most gratifying. So late as 1905 very little interest was taken in the scientific treatment of centrifugal pumps; little was known regarding their characteristics, except possibly in three or four factories, where even their meagre knowledge was guarded jealously. But, in the intervening ten years the design of these pumps has advanced from the "whittling" stage to a scientific basis, and pumps are now available, which in construction and in efficiency are on a plane with hydraulic turbines. The excellent works of Loewenstein and Crissey[12] and Dougherty[13] offer a safe foundation for all irrigation engineers.

The plain centrifugal pump with open volute continues to be used much more than pumps with fixed vanes. Plain pumps of high efficiency can be built at low cost, and they are the least of the irrigators' troubles. The proportion of vertical-shaft pumps is increasing, owing to the greater depths at which groundwaters are being developed; yet where conditions admit of its use, the horizontal pump is rightly preferred. Improvements have been made in the adaptation of impellers to the conditions of head and discharge, in the methods of balance, in the lubrication, in the reduction of clearance, and in the accessibility to the impeller. Greater backward curvature of the impeller vanes and increase of speed give flatter efficiency and input characteristics. The old open-impeller has practically disappeared. A few of the primitive style of pumps are still on the market, but with the growing appreciation of good machinery, they are being driven out.

Vertical-shaft pumps operate best on heads of from 30 to 50 feet (9.1 to 15.2 m.) per stage. The practice of using a single stage on lifts from 90 to 110 feet (27.4 to 33.5 m.) was tried extensively in 1913 and 1914, but it was found to be impracticable to run the long shafts at the high speed required. Horizontal pumps, on the other hand, can be accurately aligned, and recently-designed pumps speeded at 1800 to 2000 R. P. M. appear to operate successfully.

Vertical turbine pumps designed to go into cased wells have come into wide use. Their problem has been that of the vertical shaft bearings. Separate bearings at the joints of the discharge pipe, protected in various ways from sand and grit, have not proven successful, for enough sand could find its way into the bearings to cut them out rather quickly. But the vertical shaft fully enclosed in a line of oil tubing is long-lived and free from troubles. No longer is it deemed necessary to support the oil tubing from the discharge pipe, but the tubing is put under considerable tension in order to give it supporting power. Until recently these pumps have been built with ball or roller thrust bearings in the pump head, but they can now be obtained with hydraulic balance, a feature of design which is distinctively Californian. The latest improvement is the use of a seal just above the pump bowl, so that the well casing can be used for the discharge column.

During the early years of development of the vertical turbine pump, scant attention was given to the impellers, and the efficiencies shown in tests were uniformly low. During the last year or two, however, great advancement has been made. In a test of a new 5-stage turbine pump, with 14-inch (35.6 cm.) bowl, at the University of Arizona, in May of this year, a maximum combined efficiency of 58.2 percent was obtained for pump and motor belt-connected, the test being based on the static lift. The maximum efficiency was given with a discharge of 340 gallons (1287 litres) per minute and a lift of 26 feet (7.9 m.) per stage of pump. Chas. H. Lee, Assoc. M. Am. Soc. C. E., has reported on tests, made at Los Angeles on a 4-stage 14-inch (35.6 cm.) pump. He found the pump efficiency in excess of 70 percent for a range of discharge from 450 to 750 gallons (1704 to 2840 litres) per minute. So it is established that good performance is possible from medium-sized turbine pumps.

Vertical turbine pumps are more costly than pit pumps and are not likely to displace them on lifts of less than 100 feet (30.5 m.), except in cases where a heavy draw-down is required. The field for the pitless turbine seems to be on lifts from 75 to 250 feet (23 to 76 m.). For developing new wells, the pitless turbine has no equal.

The propeller type of pump which has short helical vanes

attached at intervals of about 5 feet (1.5 m.) along the shaft has been purchased considerably by farmers, and at least a few engineers have been attracted to it. With this type, too, the designers' efforts have been concentrated upon finding shaft bearings which would exclude the grit usually found in well water. Felt packing has been tried, as well as dead-water tubes and caps, and impellers enclosed in short slotted tubes, thru which slots water is forced to form a cushion or lubricant between the tube and the discharge column. Bronze, composition metal and lignum vitae have been tried for bearing surfaces. At present, straight guide-vanes are used, either above or below the runners. No authentic tests of these pumps have been reported; but from the fact that large engines are required to operate them, it is believed that their efficiency is low. The problem of the bearings may be solved in time, and it is likely that attention will be given to the curvature of the impeller blades and of the fixed guides, in order to increase the efficiency of the pump. Propeller pumps have an advantage in obtaining a large discharge from well casings of 10-inch (25.4 cm.) size or smaller. A peculiar feature, too, is that the speed required is not dependent upon the lift.

The reciprocating type of pump continues to find a field in irrigation pumping. The conditions, however, requiring a large discharge from a pump set deep below the surface have necessitated the development of entirely new designs. Double-acting pumps with one rod enclosed within the other and pump heads with heart-shaped cams or gears or walking-beam motion effect an overlapping of the power strokes which quite eliminates any pulsations in discharge or in power. And the triple-acting pumps recently introduced, the Glendora pump and the triple-cam Luitwieler, give continuous operation that is practically perfect. Notwithstanding their high cost, the double-acting pumps are much in favor in the foothill regions of southern California, where the lifts vary from 100 to 400 feet (30.5 to 122 m.). For the higher lifts, they are used exclusively.

Mention should be made of other types occasionally met with. The bucket elevator is still used to a small extent, as is air-lift also. It is generally recognized, however, that the air-lift is not an irrigation pump, and their number is decreasing. Freak pumps appear frequently, but after a few installations they are

seen no more. The first installation in this country of the Humphrey direct-explosion pump, an English type, is being made at Del Rio, Texas, to lift water from the Rio Grande, but this type is not suitable for pumping from wells.

An approximate estimate of the pumping practice in southern California, based on the quantity of water pumped, is as follows:

Reciprocating pumps	20	percent.
Horizontal centrifugal pumps	30	"
Vertical centrifugal pumps in pits	30	"
Vertical turbine pumps	15	"
Other types	5	"
Total	100	percent.

In Arizona and New Mexico the percentage of reciprocating pumps is much less, while that of vertical turbines is more than 15.

OIL ENGINES.

Irrigation pumping plants serving single ranches are operated by internal-combustion engines or by electric motors. Thruout large areas, electric power is not yet available, at least at low rates, and a gasoline or oil engine is the most feasible power.

The development of the gasoline engine during the past ten years has been more in the direction of multiplicity of design than in real improvements. Just now there is a movement, among manufacturers, looking to the standardization of important parts—a most worthy object. One improvement of great value has been the general adoption of the magneto for ignition and the perfecting of the magneto. The low tension magneto continues to be the most used.

But the revolutionary feature in the engine trade has been the introduction of oil engines, which are designed to burn low-gravity distillates. When, in 1912, it was realized that the cheap, abundant distillates of 35° to 45° Beaume, costing 2¾ cents per gallon in carloads, F. O. B. Los Angeles, could be utilized for fuel by slight modification of the standard gasoline engines, manu-

facturers and purchasers turned immediately to the oil engine, as the promised land in the power world. Necessity had much to do with the change, for the production of gasoline has not kept pace with the increase in the number of stationary engines and automobiles. In 1913 it was shown that the supply of gasoline was sufficient to operate the engines then in use only one-half

Fig. 6. Engine House, Pump House and Fore-bay of Plant in Salt River Valley, Arizona.

The Pump House is on rollers running on a track and telescopes back into the engine house.

hour per day, and the price of gasoline was tending upward rapidly.

The new oil engines have followed two lines of design: First, the Otto, or 4-cycle type; and second, the two-cycle type. The four-cycle oil engine is referred to sometimes by its detractors as "a made-over engine". The only important difference between it and the gasoline engine is that the oil engine preheats

the charge or introduces a slow water feed into the charge, or does both. Preheating is done by passing the intake air thru a jacket on the exhaust block or by passing a part of the exhaust thru a tubular generator between the carburetor and the cylinder. The humidifying water is introduced into the carburetor thru a needle-valve in the same manner as the fuel oil. These engines require a throttling governor; the time of ignition should be advanced more for distillates of low gravity than for gasoline, and it is desirable that the compression pressure should be increased somewhat. Many farmers have altered their gasoline engines by arranging a water feed for the carburetor or on the air intake pipe.

The effect of adding water to the charge is far-reaching. Indicator cards taken on engines, first without the water feed and then with it, show a Dieselizing effect due to the water. Instead of sudden violent explosions with high initial pressures, the gases burn more slowly and the cards show a flat combustion line for about a tenth of the stroke. With the water feed, the combustion appears to be perfect; with distillate of 40° Beaume, the exhaust, even from small engines, is absolutely colorless and invisible. Carbon deposition is reduced, and the cylinders and valves of made-over engines burning the low distillate keep cleaner than they did formerly with 50° distillate and no water feed. Also, the engines heat up less, there is less loss of heat in the circulating water, there is no preignition, and the lubrication of the cylinder is improved. As an example of the excellent service given by these oil engines, a heavily loaded engine has run steadily thru a 14-hour day without a visit from the attendant. There was no muffler, and thereby the farmer, in whatever place he might be, had the assurance that the engine was running all right. The author's tests on oil engines indicate that the fuel economy is fully equal to that of gasoline engines.[14] In Arizona the new distillates, called Tops or Gas Oil, retail at 7 cents a gallon, as against 17 cents a gallon for gasoline. Hence, the introduction of oil engines has stimulated pump irrigation greatly and has made possible the utilization of groundwaters of greater depth than was economically possible with gasoline as a fuel. Oil engines of size up to forty and sixty horsepower are becoming quite common for individual farm pumping plants.

Another type of oil engine has been developed from the two-cycle gasoline engine. The important changes have been the separate injection of the fuel oil at the end of the compression stroke, the introduction of water in the air charge, and the substitution of a hot ball or hot plate for electric ignition. The engines are prepared for starting by heating the hot ball with a blow torch for from ten to thirty minutes. The ignition being automatic, the temperature of the cylinder requires to be controlled closely, and this is done in most engines by hand regulation of the feed-water valve. Pump lubricators and friction-clutch pulleys are required, even on small engines. In California and Arizona, engines of this type have not proven entirely satisfactory, possibly on account of the asphaltic character of California oils. The difficulties have been due largely to imperfect combustion of the fuel oil. Possibly they will be remedied when more effort is made to adapt these engines to oils having an asphalt base.

Large pump-irrigation enterprises permit of large power-units. Many mutual water companies of southern California and the owners of large irrigated tracts operate plants of from 100 to 500 horsepower. Multiple-cylinder oil engines are used in some instances, but Corliss steam engines are found, frequently, in small central stations or in air-lift plants, and steam turbines and producer-gas engines have been selected in a few instances. The community pumping project at Avondale, Arizona, includes two units, one with a 2-cylinder 100-horsepower oil engine, and the other having a 3-cylinder 150-horsepower engine driving a horizontal centrifugal pump, the suction line of which is connected to 12 wells. Steam power has been handicapped by the high cost of attendance and the low fuel economy; for irrigation pumping, the transition from steam to internal-combustion engines is now almost complete.

An installation of the highest type of power machinery has just been completed at Tucson, Arizona, to furnish power to the pumping plants of the Tucson Farms Co. It consists of two 500-horsepower 4-cycle Diesel engines and 2300-volt generators. The fuel used is crude oil of 15° Beaume. It burns perfectly clean, and the consumption is but slightly over 0.4 lb. (0.18 kg.) per kilowatt-hour at the switchboard.

ELECTRIC POWER.

As early as 1900, pump irrigation in southern California had become so important as to warrant a few transmission lines thru the pumping districts. Since then, many additional lines, some of them of great length, have been built. In a few cases, the power is derived from oil-burning power plants, but to a greater extent it comes from the hydro-electric plants of the west slopes of the mountain ranges. Competition, together with the desirable character of the pumping load, has made the power rates to irrigators reasonably low. The prices paid range from 1½ to 3 cents per kilowatt-hour. In some localities a fixed annual charge is made, the amount of power used at each motor being based on a few trial measurements. In the vicinity of Bakersfield and Tulare, California, this charge is about $50 per horsepower per year. It is customary for the user to purchase the installation, including the transformers. Frequently, farmers are found taking out their motors and installing oil engines, in the belief that the engine power is the cheaper. This is true, undoubtedly, unless the farmer, thru carelessness, brings on serious engine troubles, but it is also true, oftentimes, that the inherent convenience of motor power is worth the extra cost.

In Arizona the high rates for electric power stipulated by the Corporation Commission make the use of power from public service corporations prohibitive for small farmers. The Salt River Valley project of the U. S. Reclamation Service, as now operated, includes nine pumping plants, with capacities of 10 second-feet each, all electrically driven. The Reclamation Service furnishes power also, for irrigation outside of the project. The rates paid for the power are based on a sliding scale. In the case of one company, which had three pumping plants, the average cost of the power, in 1914, was 2.46 cents per kilowatt-hour. The lateral transmission lines and all electric equipment are furnished by the consumers.

In the Grand Canyon of the Colorado there is abundant hydro-electric power for the entire state of Arizona, and doubtless some of it will be developed. Two projects, one near the Bright Angel trail and the other near Peach Spring, have been designed and efforts have been made already to finance them.

Smaller projects in the mountains of the eastern part of the state are also feasible. So it is evident that soon Arizona will follow the example of California in the utilization of hydro-electric power for irrigation pumping.

There is a close correlation between hydro-electric power development on the mountain streams and pump irrigation in the valleys lying below. The water can be used first for power and afterward for irrigation. In one instance, in Placer County, California, the water is to be used six times for power and then for irrigation.[15] In cases where only the natural flow is used for power, there can be no possible interference with the rights of irrigationists below. And in case of storage, the loss of water by evaporation is inconsiderable—quite out of proportion to the saving of floodwaters which, if not stored in reservoirs, would find their way to the sea. On years of light rainfall, however, the natural distribution of groundwater supplies along the lower courses of a river tends to disarrangement, but it is well within the functions of engineers to effect an equitable distribution of the tail waters from power plants. Irrigation, then, and the development of "white coal" power are mutually advantageous.

In designing practice, the changes during the last fifteen years have been of very little moment. The tendency has been toward higher voltages, so as to effect greater economy in the use of copper; 2300-volt motors are selected more frequently now. Motors are built somewhat lighter than formerly, and the efficiencies are just a little higher. The rating is considerably closer, but the motors are better protected against overloads and accident. Induction motors are used almost universally, most of them being of the squirrel-cage type.

ECONOMICS OF PUMP IRRIGATION.

Published estimates on the cost of pumping have been based, usually, on data collected at some selected pumping plants. LeConte,[16] Tait,[17] and Gregory[18] have contributed valuable estimates of this kind. But, the controlling factors, such as cost of wells, character and cost of machinery, rate of fixed charges, lift, acreage irrigated, duty of water, and cost of fuel or electric current, and of attendance, are so variable that every

plant presents a special problem, and it is difficult to find plants that are truly representative. Fleming published general cost data for small pumping plants in New Mexico, in 1909.[19] Etcheverry, in 1913, published an analysis of the cost of pumping in

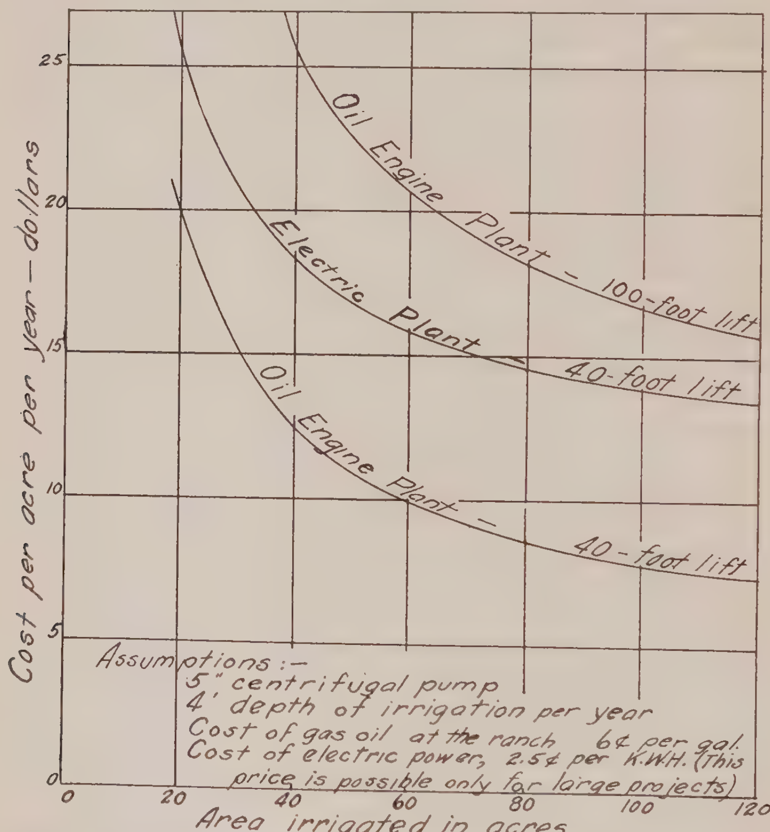

Fig. 7. The Influence of Fixed Charges on the Cost of Pumping in Arizona.

California;[20] and the author has recently published a similar analysis based on hypothetical averaged conditions in Arizona.[14]

The most surprising fact revealed by a study of cost of pumping is the importance of fixed charges. In the oil-engine plants now in use, the item of fixed charges is greater than the items of fuel, lubricating oil and attendance combined. With motor-driven plants, too, in many instances, the fixed charges

exceed the operating costs. The cause for this condition is usually not that an inordinately expensive plant has been purchased, but that the plant serves too small an acreage. There are many plants in Arizona costing over $4000 and serving less than 40 acres (16.2 hectares). To install smaller plants is a poor solution, for it is difficult and costly to irrigate with a stream of water less than 500 or 600 gallons (1890 to 2270 litres) per minute. The only rational escape from the high fixed charges per acre is to serve a larger acreage under each plant, and to use the plant continuously instead of only 30 or 40 hours a week. Since the individual rancher is limited in energy and resources to a modest area, then three or four ranchers should make use of one plant, either cooperatively or as leasers. The greatest fallacy connected with pump irrigation, at the present time, is the idea that each farmer must have his own pumping plant. As well might it be said that each ranch should have its own ditch from the river. The mutual water companies in the pumping districts of southern California are cooperative in principle; they are successful and beneficent. The further extension of cooperative pumping thru Arizona and New Mexico, and probably in California, is the highest desideratum.

In addition to reducing the cost of pumping per acre, cooperative plants offer other advantages: the groundwater supply can be developed at more strategic points, with less interference between wells and less possible litigation; competent men can be secured to have charge of the plants; and the first cost of the investment by each farmer is reduced greatly.

Comparison between the cost of pumping under various conditions and the cost of irrigation under gravity projects indicates higher cost for the former, in general. Yet this is not true universally. There are many localities of low-lift pumping where the total cost of pumped water is less than $3 per acre-foot, an amount that is exceeded frequently under gravity ditch or reservoir systems. Pumping for irrigation does not compete directly with the utilization of surface waters. Gravity projects of economic cost are developed first; pumping then follows, either to enlarge the irrigated area, or to provide water during seasons of low stream flow, or to irrigate lands not covered by the canals.

There are several other important features of pumping which should be mentioned in the present discussion. There is nothing in pump irrigation which corresponds to a reservoir dam failure. A pump may be out of commission for a week, as may a canal, but a well cannot become a menace to a village, nor can it allow the groundwater supply to be wasted suddenly. Pump irrigation, in flexibility, approaches that of reservoir projects; it is not necessary to irrigate in winter to save the water, nor at other undesirable times. And, too, pump irrigation has a far-reaching influence for higher duty of water; for reduction of water losses, as by means of ditch linings and the use of deep furrows; for clean cultivation; and, in general, for more efficient irrigation. Water-logging of land and drainage projects are not concomitant to pumping districts. Pump irrigators are never humiliated by a 45 percent loss of water in their ditch systems.

There are limitations to the lift at which pumping for irrigation is profitable. Six years ago the limit of lift for economical pumping in Arizona was less than 40 feet (12.2 m.). Today, due to the recent introduction of low-gravity distillates and the improvement in pumps, it is close to 100 feet (30.5 m.) for general farming. Etcheverry states that in California 400 feet (122 m.) may be taken as the limit for citrus fruits, olives, apples, and other orchard products; while for alfalfa, the limit is from 40 to 100 feet (12.2 to 30.5 m.), depending on the pumping conditions and the selling price of the alfalfa.

PROBABLE FUTURE DEVELOPMENT.

Except possibly in southern California, pump irrigation is still in its early stages. There are large areas where no other type of irrigation is possible. Most gravity projects, at present, need more population; but as soon as these projects are developed to the point where surface water supplies are utilized, then will the groundwaters be drawn from to extend the agricultural growth. Exceptions occur, of course, where the groundwaters are too saline even for admixture with river supplies. But the outskirts of gravity projects are especially favorable for pump irrigation, on account of the positive and constant recharge of the groundwaters due to the canal systems and downward per-

colation from fields. The great possibilities for development by irrigation pumping in the Sacramento Valley have been pointed out just recently by Kirk Bryan.[21] Even in southern California Tait anticipates an increase in irrigated area in the eight southern counties from 745,486 acres (302,000 hectares) to 1,950,000 acres (788,000 hectares), in part from the development of pumping.[22] The growth of pumping will occur faster in States like Arizona and Nevada, where surface supplies are meagre or unfavorable to development, but will extend to States such as Idaho and Montana later on.

A large field of usefulness is open to engineers in furthering and directing the development of pump irrigation. Engineering geologists can point out the areas of economic and permanent supplies and their estimates of safe yield are of great value. Farmers need the help of consulting irrigation engineers, and there are many farmers, well-to-do, who will gladly pay the price as soon as the engineers have demonstrated, in a few cases in each locality, their ability to solve pump irrigation problems in a superior manner.

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DISCUSSION

Mr. Scrugham.

Mr. J. G. Scrugham* (verbally) referring to page 418 of the paper, called attention to the relation of topography to ground-water distribution in a certain part of Nevada. In the draws or stream-beds of the higher bench-land there, the water-table is nearer the surface than elsewhere, being only 5 to 20 feet below ground surface. It is desired to irrigate adjacent valley lands, the drop of the ground surface being 40 to 60 feet per mile. He desired information as to the feasibility of siphoning the ground-water from the bench-land to the valley.

Also he desired to know whether the temperature of well water is a criterion as to the quantity of flow to be expected. He cited a case of a flowing artesian well with a temperature 78° Fahr. and with a large flow, and of another well nearby, with a temperature of 78° and a large flow; while a third well, only a quarter of a mile away, with colder water had a very low flow.

Mr. Lee.

Mr. Chas. H. Lee,† Assoc. M. Am. Soc. C. E. (verbally), replied to Dean Scrugham that siphoning ground-water had been tried by the Spring Valley Water Company near Pleasanton, in the Livermore Valley, California. It worked well for several years, but finally lowered the water-table to an elevation below that of the siphon intake.

Mr. Lee stated that the temperature of shallow ground-water approaches closely the average annual temperature of the air; deeper waters are warmer; deep-seated waters are usually very hot from having been in contact with heated rocks.

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† Civ. and Hydr. Engr., Los Angeles, Calif.

Mr. Lindsay Duncan,* M. Am. Soc. C. E. (verbally), referring to the question of Dean Scrugham, stated that he had encountered the same problem of ground-water distribution in eastern Nevada. Here it was solved by sinking a shaft and driving a tunnel; the combined flow from the underground waters and the small surface stream being 2 to 3 cubic feet per second at 40 feet underground. Mr. Duncan.

Mr. J. C. Nagle,† M. Am. Soc. C. E. (verbally), stated that in his opinion there is no relation between the temperature of well water and the quantity that can be developed. The differences in temperature are to be accounted for by the variation in the geological formations at the sources. Mr. Nagle.

Mr. P. M. Norboe,** M. Am. Soc. C. E. (verbally), stated that in the Coastal region, in 1860, hot and cold artesian springs were found near each other. In Carson City, Nevada, cold artesian wells and hot springs occur within less than 2 miles of each other. Mr. Norboe.

In the matter of power for pumping water he stated that in the Lodi District, California, where wells were being pumped by electric motors, the motors are now being replaced by oil engines because of a raise in the rates for electric current.

Speaking of the cost of irrigation water, he referred to much information on this subject in Mendenhall's Water-Supply Paper No. 322.

He spoke of a highly developed region in California where the supply for wells was by slow percolation from the delta fans of two rivers, one on each side of the territory, which supply has become exhausted. Constant pumping has drained the ground-water out faster than it came in, until it is necessary to raise the water 250 feet instead of 200 feet as formerly. It is proposed to pump water from the sands of the delta fans in the rivers, but no authority can be found having power to permit this.

Mr. F. E. Trask,†† Mr. Am. Soc. C. E. (verbally), stated that in southern California the usual method of developing the ground-water supply is to drive tunnels with gathering chambers, and remove the water by gravity flow. Formerly no bulkheading of tunnels was done, and consequently the gravels were drained and the supply became unsatisfactory. This difficulty has been eliminated in the present practice by installing bulkheads and recharging the gravels by the use of gates. Siphons are not used. Mr. Trask.

He stated that in his experience there is no relation between the temperature and the volume of well water. He has found, in general, that the courts will grant water privileges so long as there is no interference with other supplies that are being used.

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† Chairman, Board of State Water Engineers, Austin, Tex.

** Assistant State Engineer, Sacramento, Calif.

†† Cons. Civ. and Hydr. Engr., Los Angeles, Calif.

Mr. Gideon. **Mr. A. Gideon,*** M. Am. Soc. C. E. (verbally), stated that due to the greater depth of filtration, the hot water from deep wells has been found to be purer bacteriologically than the water from shallow wells.

Mr. Mead. **Mr. Elwood Mead,**** M. Am. Soc. C. E. (verbally), stated that in parts of Australia underground water is the sole source of supply for all uses. An area one fourth the size of the United States is supplied by several thousand wells. Owing to the fact that great variations in temperature and in pressure occur in these wells, the theory is advanced by Prof. Gregory of Glasgow, and others, that this water was imprisoned in past geologic ages and therefore is non-recurring. The wells vary from 1000 ft. to 4000 ft. in depth, and the temperatures of some are as high as the boiling point.

Mr. Lee. **Mr. Chas. H. Lee,** Assoc. M. Am. Soc. C. E. (by letter), stated that the author has outlined the subject of ground-water utilization in a very comprehensive manner. This is a field of modern endeavor which in America is just reaching a stage of coherent expression. As a branch of applied science, it still is more or less a collection of uncorrelated facts whose application is by the old-fashioned method of "rule of thumb". During the last ten years, however, great progress has been made both in methods of preliminary investigation and in practical development of ground-water supplies; and, as the author says, the time is now ripe for a comprehensive book on the subject. Both the French and German branches of the engineering profession have produced such works, which (together with a great mass of unorganized data and partially formulated principles available in this country) should furnish ample basis for a pioneer effort in the presentation of ground-water supplies in America.

One step which has been needed to give the subject of ground-waters a place among the applied sciences is the development of methods for quantitative determinations which may be relied upon for the planning of water-supply projects from underground waters. Mr. Lee has watched closely the efforts in this direction made during the last ten years, and himself has had exceptional opportunities to experiment upon and test out the practicability of such methods. It is his belief that when judgment is used in the choice of method and in the gathering and analysis of data, in many instances results are obtainable at a reasonable cost which are comparable in accuracy to similarly executed investigations of surface-water supplies. However, the problem is not one susceptible to a uniform method of solution. Climatic conditions, geology, vegetation, and streamflow characteristics all introduce vital factors which must be considered. The clear understanding of the situation involves a clear understanding of structural geology, plant physiology and of climatology, as well as engineering subjects. The engineer has the broad training which enables him to attack such problems, and Mr. Lee believes that the subject holds forth to the engineer a new field of specialized endeavor.

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** Professor Rural Institutions, Berkeley, Calif.

In general there are three types of occurrence, as follows, of economic ground-waters susceptible to quantitative investigation of rates of supply: Mr. Lee.

1: The so-called "underground stream", which is a distinct movement of ground-water in a definite direction through a subterranean channel composed of a porous medium confined and limited laterally and vertically by relatively non-porous materials;

2: A broad, generally diffused movement of water in a definite direction through a porous medium of relatively unlimited horizontal extent;

3: The so-called "underground lake" or "reservoir" formed by a structural basin in relatively pervious material, filled with porous alluvial or other debris containing water, which has a definite and regular inflow and outflow.

The first type probably is best investigated quantitatively by the well-known "Slichter method"; which consists of determining the cross-section of the porous medium, its porosity and size of grain, and the rate of movement of the ground-water by varying electrical resistances. The results obtained by this method usually are unsatisfactory on account of the difficulty of obtaining complete data relative to the porous medium, and also because of the uncertainty of the results secured with the electrical equipment. In some instances, this method may be supplemented by measurements of streamflow losses and other sources of supply, so planned as to give an independent check on the results.

The second type may be investigated by a number of methods; each case presenting its own problems depending upon the magnitude of the proposed development, the source of the ground-water, the character of the ground-water outlet, the nature of the geological formation, etc. The most notable investigation of such a ground-water supply is that made on the south slope of Long Island by Walter E. Spear, M. Am. Soc. C. E., in connection with studies for the additional water-supply of New York City.

The third type may be studied quantitatively either by determining the total percolation into the porous material of the basin from various sources, or by investigating the ground-water losses. The former method is preferable where the principal source of percolation is stream-flow from which channel losses can be measured accurately; or where the percolation is largely and evenly distributed throughout the year, and forms the major portion of the supply. The latter method is by far the best under arid conditions, for which it will displace eventually all others.

The most important single element of loss from ground-water basins in arid regions is the transpiration from vegetation. Only in very recent years have botanical and agricultural researches attacked this subject; and as yet consideration has been confined by the botanist to a study of processes and influencing factors and by the agriculturist to relative amounts for short periods or to total water requirements of certain field crops during the growing seasons. The extension of the latter work to

Mr. Lee. natural vegetation and the development of principles governing the relation of transpiration to free water evaporation are needed imperatively. The condition of vegetation dealt with in ground-water studies is one of ample water-supply, even in desert regions. The roots are within easy reach of a permanent water-plane; and no restriction exists upon water consumption except, in special cases, high alkalinity of the ground-water.

The types of vegetation for which data are most needed include trees such as the willow, sycamore, alder, cottonwood and oak; shrubs such as the wild rose, mesquite, sage-brush and other desert varieties; and low-growing plants such as salt grass, fresh-water meadow grasses, tules, reeds and rushes, samphire and various fleshy salt-marsh varieties. It is hoped that the need of this information may be brought to the attention of botanical investigators and that the next ten years will see a substantial advance in securing it.

Mr. Lee wished to emphasize the opportunity offered for over-year storage by the great debris cones of arid and semi-arid regions. The greatest hindrances to the development and use of water resources of such regions are the wide annual fluctuations in rainfall and particularly in run-off and the high rates of evaporation. Water-spreading, if planned properly, could be made to utilize much of the available storage capacity of such cones for the replenishment of pumping supplies during dry years. To be most effective in this respect the spreading-ground should be located well up the slope of the cone, in order to prolong the period of storage as much as possible. On the large cones of southern California, the effect of large absorption on the upper cone is not felt on the lower cone for two or three years; and during this period the water is not subjected to evaporation or to other absolute loss.

In southern California the violence of flood-flows is so great that without temporary detention reservoirs, water-spreading will be confined to the surplus flow during moderate flood stages. Considerable surplus water of this character is available on many southern California streams. In view of the great expense and difficulty of preparing temporary storage sites, the possibility of spreading water from the flood peaks is very remote. It may be said also in passing, that this eliminates water-spreading as an important factor in flood control.

The author states that the use of wells dug to full depth is decreasing. While this is true of the coarse alluvial debris formations, yet in material which stands readily and yields water slowly the dug well is still most popular. A good instance is the decomposed granite in place met with in many of the back country valleys of San Diego County, California. Wells in this material reach depths of 30 to 60 feet, of which 10 to 40 feet may be below the water-plane. The yield of such wells often is sufficient for the irrigation of small areas. Boring or tunnelling laterally from such wells often is resorted to successfully for the purpose of increasing the yield.

There is one feature of ground-water utilization which the author

has not touched upon, namely, the growing need of public control and administration of ground-water sources, particularly of the underground reservoir type. Mr. Lee has knowledge of several important basins in southern California that are being drained steadily by a pumping draft in excess of their annual recharge. At present there is no relief for such conditions but expensive litigation. Also, he has observed many of the desert valleys of southeastern California, Arizona and New Mexico, in which settlers are spending large sums in the aggregate in well-drilling operations and in the preparation of land for irrigation. The water-supply possibilities of many of these valleys are sufficient for the irrigation of but a very small percentage of the available land, and many of the investments of this character are dead losses. Mr. Lee.

The California courts have abandoned completely the old idea of the water beneath a man's land being part of his land in the same sense as a mineral deposit. The fact now is recognized that there is a common source of water supply from which all overlying land owners draw, that all have a proportional share in its use, and that a lowering water-plane is the result of the combined draft from all wells. The fact also is recognized that the inflow into an underground reservoir, the broadly diffused water in the basin, and the outflow therefrom, all are different aspects of one common source of supply. With these ideas established firmly in court precedent, legislation designed to control the development of ground-water sources for the public good should be an easy step. As the knowledge of ground-water occurrence and behavior increases, such control is becoming more and more within the range of possibility; and Mr. Lee believes that at no distant date serious public consideration will be given to such control of underground water resources.

Mr. W. H. Code,* M. Am. Soc. C. E. (by letter), stated that from 1892 to 1902 he was located in the Salt River Valley, Arizona, as Chief Engineer for the Consolidated Canal Company; and that during the latter part of that period the valley suffered from a succession of dry years when the Salt River during the irrigation season at times would fall as low as 150 cubic feet per second, that being all the water available for the irrigation of a cultivated area approximating 113,000 acres of land. Mr. Code.

The year 1900 was an extremely dry one, the entire quantity of water diverted by all the canals of the valley being only about 175,000 acre-feet; whereas, they should have diverted (including the amount to cover seepage losses) at least 500,000 acre-feet for the proper irrigation of the cultivated area. The situation became so alarming that all classes of citizens were called together in a committee, to devise ways and means for obtaining relief and increasing the water-supply. Due to the activity of the Committee, the Salt River Valley was one of the earliest sections to receive the benefit of the Reclamation Act which was passed in 1902; with the ultimate result that the $12,000,000 Salt River Project,

* Los Angeles, Calif.

Mr. Code. including the magnificent storage reservoir created by the Roosevelt Dam, stands now between the farmer and the drought-stricken conditions which prevailed during the earlier years. This injection of facts that are well known to many readers is made to lead up to the question of pumping and its importance as an auxiliary supply.

Among the many plans investigated or considered in the Salt River Valley during the dry years was that of developing underground water by means of pumps; but no data then were available as to the probable success of deep wells. To the Consolidated Canal Company belongs the credit of doing the pioneer work in sinking such wells and in installing the first modern, direct-connected, electrically-operated centrifugal pumping plant in the Valley. This plant, drawing upon the abundant underground water-supply that was found to be available even during lean years of surface water-supply, was followed by three other pumping plants of a similar type; and about 3000 acres of an alfalfa farm was created on lands some of which had been seeded previously many times, but had failed each time to produce a crop because of inability to obtain river water at critical periods in the plant growth.

The advantages of these pumping plants, and others that were installed subsequently, were in insuring a stand of alfalfa on land when once seeded. After the alfalfa became well rooted it could stand a considerable period of drouth, but it was essential in its early stages that a certain assured water-supply should be available, hence the value of pumping as an auxiliary supply. It is altogether probable that the entire area of approximately 113,000 acres which was in a state of semi-cultivation in 1900 could have been cared for by the building of the Granite Reef Diversion Dam across the Salt River in order that the normal and flood flows could be properly diverted, and the installation of pumping plants in the pumping areas to furnish the necessary auxiliary supply from underground sources.

Mr. Code is not aware of any other instances where so great an area of land seemed destined to return in a large measure to a desert condition, with a majority of the farmers, merchants and bankers in a state of anxiety and financial stress; while under large areas of the land so threatened were located underground reservoirs of water sufficient to supply the adequate supplemental water-supply needed.

The experience thus gained in the Salt River Valley was of subsequent value to him when, in the employ of the Government, it became his duty in 1902 to recommend a plan for relieving the drought-stricken conditions on the Pima Indian Reservation in the Gila River Valley, Arizona. Here again no data were available as to the probable quantity or permanence of the underground water-supply. Actual experiment through the installation and operation of the initial steam-driven Sacaton pumping plant, together with the drilling of many test wells on the reservation, demonstrated that the underground reservoirs bordering the Gila River were as extensive as those in the neighboring Salt

River Valley. The results of these experiments induced former Commissioner of Indian Affairs, F. E. Leupp, with the approval of the then Secretary of the Interior, James R. Garfield, to obtain over half a million dollars from Congress for the construction of a flood-water canal from the Gila River, and the installation of the ten modern electrically-operated direct-connected vertical centrifugal pumping plants, referred to in the author's paper. This work was performed by the Reclamation Service in cooperation with the Indian Service. The Sacaton pumping stations are located at intervals immediately below the gravity canal, some 10 miles in length, back from the Gila River. This plan contemplated ultimately a substantial low concrete diversion dam across the Gila River, in order that the diversion of the flood-waters could be accomplished in a proper manner; and it is hoped that congressional appropriations during the next session of Congress will be sufficiently liberal to supply the Sacaton irrigation system with this vital feature. Mr. Code.

The importance in the Gila Valley of pumping plants as an auxiliary to flood-water irrigation cannot be too strongly emphasized. In common with most streams of the southwest, this river is torrential in character and at times carries large quantities of water and much silt in suspension. Again, during dry years, the river will be without flood waters during almost the entire irrigation period. Irrigation from such a stream cannot but prove more or less of a failure unless a supplemental supply can be obtained; and underneath thousands of acres of land bordering the river, such supplemental supply can be found within reasonable pumping lifts of 40 to 60 feet.

There has been more or less agitation concerning the construction of a storage reservoir on this river, but such works require years for completion. In the meantime, great areas of land must remain in a desert condition; and this land could be cared for if low concrete diversion dams were constructed across the river at a few points along the stream, above lands previously demonstrated by actual experiment (as the Sacaton) to have underground reservoirs of water which could be drawn upon by pumping and thus reinforce the gravity supply of river flood waters. All such pumping works would be needed even in event storage reservoirs should be built at a later date. The territory proposed to be covered by this combined system should be tested thoroughly by drilling wells at different points, and carrying on pumping tests at every well to determine the lift, quantity, character, and probable permanence of the underground supply. It is especially important that frequent analyses be made of the pumped water in order to determine its chemical constituents.

At the present time, Mr. Code is one of a firm of consulting engineers engaged in reclaiming a 72,000-acre tract of land in Fresno County, California, which lands embrace the lower Kings River for a distance of about 17 miles. Here again the plan proposed is a gravity canal system from the Kings River, in order that the flood waters of the

Mr. Code. winter and spring months may be utilized on the lands, while underground waters are to be drawn upon by many deep wells located on the land. At present these wells are flowing artesian wells yielding 1 to 2½ cubic feet per second; but pumping from them in all probability ultimately will be resorted to.

The above instances are cited to emphasize the importance of underground water-development as an auxiliary supply to flood-water irrigation. There are scores of streams in the West where irrigation has been limited to the area that can be irrigated successfully by the streamflow existing during the major portion of the irrigation season. The flood flows of these streams, however, may last for only two or three months of the irrigation period, and could be used most advantageously if pumping plants were installed on the lands bordering the stream, to supplement the gravity supply.

The author undoubtedly is correct in his statement that a large field of usefulness is open to engineers in directing the development of pump irrigation.

Mr. Eaton. **Mr. E. C. Eaton,*** Mem. A. I. E. E. (by letter), stated that he believed it is not known generally that 60 per cent of the water-supply of the Panama-Pacific International Exposition was developed independently of the supply of the Spring Valley Water Company. This supplementary supply of the Exposition is developed from underground sources in the Richmond District, about 6 miles from the Exposition grounds, by means of six wells giving a combined supply of 1,500,000 gallons per day.

The watershed or catchment area of these wells comprises an area of about 4 square miles. The soil is a fine, uniform, blown beach-sand of 0.18 m/m effective size, and with a uniformity coefficient of 1.5.

There is an underlying stratum of clay with its upper surface at 60 to 90 feet below the ground surface; and the supply forms a natural underground stream flowing slowly toward the ocean with an estimated velocity of 10 to 30 feet per day.

Normally, the water stands at an average depth of seventeen feet below the surface, and the six wells were put down only as far as the clay stratum. Considerable difficulty was experienced in keeping the fine sand from the wells, until, after some experimental work, a type of well was designed which has fulfilled the requirements perfectly and since has been adopted by the city of San Francisco.

This type of well consists of two casings, 16 in. and 22 in. in diameter, put down concentrically and perforated with burred slots 1/32 in. wide, the space between the two casings being filled with the mixture of sand and fine gravel determined by experiment as the best suited to hold back the fine material.

Although no trouble was experienced from clogging of the sand filler between the casings, the large space between the casings (3 in.) was left so that in case clogging did occur, the filler could be removed

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with an air lift, washed and returned. However, no trouble has been experienced from clogging. The maximum velocity allowed in designing the perforations was 0.5 feet per second. On a test of one of these wells, 60 feet in depth, a discharge of 250 gallons per minute was obtained with a drawdown in the water surface of 12½ feet and with no sand in the discharged water. Mr. Eaton.

Vertical turbine pumps were used of the type mentioned by the author as having separate bronze bearings at the joints enclosed in boiler tubing; but these pumps were very unsatisfactory, as even a small amount of sand was sufficient to cut away the bearing. The bronze bushings were replaced by lignum vitae, which were found to be much more satisfactory. The wells are all located in an area 650 feet square, and from February 20, 1915, to September 20, 1915 (the present date), 185 million gallons have been pumped from them with a lowering of the normal water-plane of only four feet.

The well of the type described was drilled by the Exposition forces by means of the hydraulic process. The casings were forced down in the usual manner by means of levers exerting a five-ton pressure on the casing and the sand was excavated from the inside by means of a water-jet pump made up from standard 2-in. piping. The total cost per lineal foot of this well was $3.89, of which $2.75 was for casing and material; and the well was completed in four days. The best contractor's bid for these wells was $7.50 per foot, thus showing a considerable saving by this process in this particular class of material over the ordinary well-drilling method.

During the early experimental work, before the type of well mentioned above was adopted, the sand that collected in the well was removed without taking out the pump by means of an air-lift consisting of a 1¼-in. discharge pipe and a ½-in. air pipe. This method worked very satisfactorily and pumped out a well that had sanded up from 30 to 40 feet in three hours, most of the time being used in getting the equipment in place. From the action of the air-lift in this instance, it is thought that between the allowable limits of submergence, this method of removing sand and gravel in well-boring would be superior to the water-jet, as the full bore of the discharge pipe can be used with no interior obstructions and a much higher percentage of sand and gravel is contained in the discharged water.

Mr. H. K. Palmer* (by letter) stated that the author mentions the fact that caisson or dug wells are used to a less extent than formerly. The reason for this is because such wells cost much more than driven wells. However, where the ground is composed largely of boulders in a loose formation, it is impossible to drive or drill wells and the caisson or dug type of well must be used of necessity. Mr. Palmer.

The United States Indian Service has put down three caisson or dug wells using a different type of construction in each of the three. The

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Mr. Palmer. first one is at Pala, San Diego County, California, on the bank of the San Luis Rey River. In this well a concrete caisson was used, its dimensions being 8 ft. inside diameter, 14 in. thick, 14 in. above the cutting edge, and decreasing gradually to 8 in. thick at a height of 50 ft. above the cutting edge. The caisson as it sank was cast in sections or rings 4 ft. 6 inches long, each ring being reinforced with three hoops of $\frac{3}{4}$-in. square twisted reinforcing rods and with sufficient upright rods to support the weight of the caisson below with a factor of safety of 5. The upright rods hooked into the uprights of the section below to form continuous rods. The purpose of these rods was to avoid the danger of breaking the caisson should it become wedged between rocks at a considerable distance above the bottom. The concrete mixture used was 1 cement : 2 sand : 4 stone.

Because of the roughness of the forms, the caisson rarely sank quietly as the rocks were removed from beneath it, but instead dropped to place suddenly as the larger rocks were blasted out. The greatest drop was 26 inches, but no injury was caused by it. On account of the looseness of the forms and the large stream of water pumped (as much as 3½ cubic feet per second at the conclusion of the work) there was considerable caving of the ground around the caisson. The derrick was supported across the well on a truss 30 feet long, but at one time one end of this truss was threatened with undermining. An attempt was made to stop the caving by packing brush between the wall of the cavity and the caisson, but this method was not successful; and most of the brush was carried beneath the cutting edge, and the rest of it had to be removed in order to dislodge some rocks that bound and held the caisson.

The caisson was sunk to a depth of 43 feet or 33 feet below water level, when the work was suspended for a few months. On renewing operations it was found that the caisson had "frozen". The cavity around it was back-filled and the caisson was anchored to this back-filling to prevent its settling any further; after which the excavation was continued to 65 feet depth by means of timbering, using 6-in. by 6-in. timbers arranged in an octagon form.

Before the well at Pala was completed, another one (mentioned by the author) was begun at Banning. In order to avoid the caving of the ground around this well a shield was used; and as the shield advanced, 2-in. wooden laggings were placed inside the cavity. The laggings were suspended from the top by iron rods to prevent a tendency to fall, and also were braced to withstand the pressure caused by forcing down the shield with jackscrews. In the shield, provision was made for driving laggings ahead, in order to prevent the entrance of gravel while removing rock from other parts of the cutting edge. However, it turned out that the formation was so firm that there was no tendency to caving, so the laggings ahead of the cutting edge never were used. Water in very small quantities was encountered at a depth of 40 feet. The water increased to 2 cubic feet per second at a depth of 125 feet, when (on

penetrating a stratum of clay) the stream became too great for the pump to handle. Mr. Palmer.

This well was completed by lining with circular concrete blocks, removing the wooden laggings as the concrete lining advanced. It was found then that large cavities had washed out behind the laggings, in some cases as much as 9 feet deep, but because of the firmness of the ground there had been no general caving. Had there been a general cave-in as there was all the time at Pala, the 2-in. laggings would have been too light.

After completing the well at Pala, a third well was started in very similar ground 12 miles above on the bank of the San Luis Rey River, at the Rincon Indian Reservation. In that well, steel sheet-piling was used to avoid caving. From the ground surface to the water-level, the well was lined with wood. The sheet-piling was cut in 15-ft. lengths, and the first ring of sheet-piling was started inside the wood lining. Because of the rocks, it was impossible in most cases to drive the piling ahead of the excavation. When the top of the first ring of sheet-piling came within 2 feet of the bottom of the wood lining, a second ring of piling was started with a diameter about 18 in. less than that of the first ring. Similarly, a third ring was started later inside the second ring. This method of using smaller rings decreased the friction on the piles and made the driving easier.

However, despite all efforts to prevent caving, a large amount of ground caved around the well and it was necessary to jack up the derrick each morning. The wood lining was carried down with the caving earth, and despite all efforts to hold the lining by tying it to timbers on the surface, more lining had to be added above that carried down.

The first ring of sheet-piling tended to settle similarly, but it was easier to hold it up than the wood lining because of its greater smoothness. The well was sunk to a depth of 47 feet and then lined with circular concrete blocks 6 in. thick, the inside diameter of the lining or curbing being 6 ft. After the concrete blocks had been laid to the top of a ring of sheet-piles, the piles were pulled out and the space behind the blocks back-filled with coarse material, if not already back-filled by the caving.

To sink a well in very loose ground by the method last described, it is advisable to carry the derrick on a truss,—the longer the better. The ground for some distance around the well then can be excavated for a few feet of depth with scrapers instead of buckets. Mr. Palmer knows of no way to avoid caving entirely, and the best method to use in well sinking, is that which will handle the material most cheaply. The truss should be made strong enough to carry some of the sheet-piling, in addition to carrying the pump and the usual load carried by the derrick. As most of the caving is caused by the rise and fall of the ground water, a large part of it can be avoided by carrying forward the well excavation continuously for 24 hours per day; though this continuous construc-

Mr. Palmer. tion will be difficult to maintain because of pump accidents, and because of the necessity of changing to larger pumps as the flow increases.

For shallow depths in a loose soil composed of boulders and gravel, he prefers the sheet-piling method of constructing dug wells. In such a formation, the shield method would be very difficult because of the caving. Where no caving is probable, it might be possible to drill the well; and if drilling could be accomplished successfully with not more than two or three attempts, it still would be cheaper than the dug method.

Mr. Smith. **Mr. G. E. P. Smith**, in closing the remarks, said that, in general, there is very little significance attached to the temperatures of well waters. It is true, in general, of spring waters that the temperature is indicative of the depths thru which the waters have passed. The increase of temperature with depth varies widely, being from two thirds of a degree to two degrees Fahrenheit per hundred feet. The occurrence of hot and cold springs in close proximity is common.

Fluctuations of temperatures, in the case of well waters, have a peculiar and important significance. They indicate activity in groundwater, and periodic recharge, and therefore justify extensive development by pumping, with temporary lowering of the water plane. These fluctuations are associated usually with natural fluctuations in the water plane. They are characteristic of the ''underground streams'' defined by C. H. Lee in his discussion, and particularly of the upper and middle portions of his ''underground lakes''.

A rancher on the Rillito River, four miles north of Tucson, kept a record of the temperature of his well water from 1895 to 1915. The record shows the normal temperature (June) to be 72.5° F. Percolation or recharge of flood-waters during the summer rains raises the temperature one or two degrees, while percolation from the cold winter floods lowers the temperature from two to five degrees below normal. The depth of the water plane below the surface, as shown by the record, ranges from 19 to 40 feet.

Tunneling as a means of well improvement is more applicable to rock and consolidated formations than to loose, open, deep gravels of the Western valley type. The author has observed many cases in which ranchers have driven tunnels outward from their wells with scarcely any resulting benefit, while neighbors have driven their wells deeper to tap additional gravel strata and have increased the yields greatly.

Mr. Lee has called attention to the need of legislation governing the use of ground-water and the administration of ground-water supplies. This need has become imperative in California and is becoming equally so in other states. It is well, perhaps, that such legislation did not become fixed many years ago, since many erroneous beliefs would have been crystallized into law. Yet, because of the rapid development of groundwater supplies, the time is near at hand when all ground-water rights must

Mr. Smith.

be adjudicated and recorded, and further appropriation of ground water must be controlled. Definite legislation is needed urgently to supersede the present uncertain judicial law or lack of law, and administrative machinery for the control of ground-water supplies must be devised. Most of the Western states, including Wyoming, Idaho, Oregon and California, have fairly satisfactory water codes and administrative boards or commissions for the regulation and control of surface waters. In those states the functions of the water boards should be enlarged so as to include ground-water supplies. Other states, including Arizona, need complete water codes, covering both surface and underground waters.

Paper No. 38

DUTY OF WATER IN IRRIGATION.

By

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INTRODUCTION.

Duty of water is unique in one respect: no other subject connected with irrigation covers so broad a field. It has to do with the legal phase of irrigation in such matters as the definition and settlement of water rights, with the administrative phase in the equitable apportionment of public water supplies, with the engineering phase in the determination of capacities of reservoirs, pumps and channels; with the economic phase in the prevention of waste and the attainment of the highest possible efficiency; and with the agricultural phase in the maintenance and control of soil moisture in such manner as to produce large yields of crops of good quality.

In this paper the usual number of subdivisions have been made without special reference to the classification outlined above. Nevertheless, the discussions of many of the subheadings show indirectly, at least, their relation to such phases.

On account of limited space, the following discussion of this subject is confined to the practice and conditions which prevail throughout the irrigated districts of the United States of America. For the same reason it has been found necessary to eliminate much of the detailed information which otherwise might have found a place in the paper. Notwithstanding these limitations, an earnest effort has been made to present the broader aspects of the subject accurately and in such a way as to show their proper relation to each other and to other phases of irrigation and irrigated agriculture.

DEFINITION AND UNITS OF MEASUREMENT.

Duty of water in irrigation usually expresses the relation between a given quantity of water and the area of land which it serves. Two methods are in use for measuring the amount of water delivered for irrigation. One of these is a time rate of delivery, allowing a given volume per unit of time, while the other considers the volume as the principal factor with the rate of delivery subordinated to it. In English-speaking countries the former method is expressed as the cubic foot per second of time, the miner's inch, and the U. S. gallon per minute. Volumetric measurements are expressed as the acre-foot and the acre-inch. The unit of land is almost without exception the acre. In countries where the metric system is adopted the units used are the cubic meter per second and the liter, while the unit of land is the hectare.

The term duty of water in irrigation, as ordinarily understood, is sometimes qualified by various prefixed adjectives. As for example, the maximum use or lowest duty represents the largest quantity of water per acre which can be used under the authority of a State, court, or other tribunal, or under the terms of a water right contract. The highest possible use or maximum duty represents the quantity of water which plants require to mature a crop of a good yield when all waste of whatever kind is eliminated. The gross duty usually refers to the average duty per acre of an entire canal system and includes all transmission and other losses of water. The net duty usually refers to the amount of water per acre applied to fields and farms when all transmission losses between the intake and the margin of the field or farm are deducted. The optimum duty represents the largest possible profits in soil products from the use of a given volume of water, such as an acre-foot, regardless of the area of land on which it is applied.

Place of Measurement.

State officers who are required to apportion the public water supplies within their respective jurisdictions, usually regulate the diversions at or near the intake and apportion to each a known continuous flow in accordance with the predetermined duty. This necessitates not only estimates or measurements at the intakes but frequently the installation

of automatic recording devices by which continuous records of the discharge are kept. Likewise engineers and canal superintendents make similar measurements at the intakes of canal systems and main laterals to determine the daily flow for the purpose of distributing to each user his proper share of each day's supply. Such records of intake discharges necessarily include all transmission losses. For each thousand second-feet so diverted, not more than six hundred second-feet may be delivered to the farmers under the system. Notwithstanding this difference between intake and delivery discharges, an officer who acts for the State, district or community, is required to consider mainly the quantities of water taken from the streams or other sources of supply. The farmer, on the other hand, who is dependent on such supply, is chiefly concerned with the amount of water which is delivered through his headgate. It is, therefore, obvious that duty of water on any canal system as determined by a State officer may be quite different from that on any farm under the same system. The former is sometimes spoken of as the gross duty and the latter the net duty.

DETERMINATION OF MAXIMUM QUANTITY ALLOWED.

The highest duty will be considered briefly under another heading. Considerable space is here given to lowest duty on account of its importance to arid States in relation to their irrigation development. The water supply of arid regions is limited in volume and in consequence measures must be adopted to control and regulate its use. By the exercise of this control on the part of arid States the flow of streams is apportioned to those entitled to receive water in accordance with a predetermined amount which shall be used and this amount in turn is fixed by various agencies authorized to perform such duties.

It is not germane to this article to discuss the methods employed in the adjudication and protection of water rights. The discussion will be confined to the agencies and methods which affect duty and more particularly to those which place restrictions on the quantity of water which can be used in irrigation.[1]

[1] Use of Water in Irrigation, by Samuel Fortier. McGraw-Hill Book Co., New York.

1 State Laws. The statutes of Wyoming, Nebraska, Oklahoma, New Mexico, and South Dakota restrict the use to a maximum quantity of 1/70 of a second-foot per acre. The maximum limit is placed at 1/90 of a second-foot per acre in North Dakota, while it is 1/50 of a second-foot in Idaho. There is a similar limitation in Nevada, three acre-feet per acre being the maximum allowance.

2. State Control. The control which is exercised by a State through administrative officers and special tribunals may likewise affect the duty of water in various ways. In many of the western States the apportionment, measurement and distribution of the appropriated waters are in charge of State officers who are required to distribute the flow of streams in accordance with adjudicated rights. This, however, does not mean that these officers have no discretionary power, for they frequently operate under laws sufficiently elastic to permit them, to a considerable degree, to administer these laws in such a way as to secure a better use of water than could be obtained by adhering strictly to a predetermined and assumed duty, and in this way confer greater benefits on the water users as a whole.

Another form of State control may be exercised by State Land Boards in examining and approving the duty of water on lands under Carey Act projects. In Idaho, for example, the prevailing duty under such projects is one second-foot of water for each 80 acres of land, delivered at the heads of the farmers' laterals.

State control is likewise exercised through special tribunals or water courts. In Wyoming this special tribunal is called "The Board of Control" and it is justly entitled to the highest praise for its efficiency. From the time this Board was organized, in 1891, up to January 1, 1914, it has adjudicated 12,500 rights to the use of water. These rights serve 1,510,000 acres. Considering the small number of its decisions that have been appealed, no other court can show so good a record.[2]

3. Court Decisions. According to the irrigation census of 1910, 35 per cent of the land irrigated in 1909 was under rights that had been adjudicated by the courts, approximately 6 per cent under certificates from the State and 7 per cent

[2] Use of Water in Irrigation, by the writer.

Duty of Water in Court Decisions in Montana.

Name of Stream	Date of Decree	Miner's Inches of Water	Acres of Land
Carbon County			
Sage Creek	Jan. 7, 1901	565	495
Cole Creek	Mar. 14, 1902	720	720
Red Lodge Creek	July 21, 1904	6,683	6,683
Rocky Ford Creek	Aug. 21, 1903	51,916	51,886
Blue Water Creek	Feb. 29, 1904	2,466	2,466
		62,350	62,250
Ravilli County			
Eight Mile Creek	May 27, 1897	930	1,353
Lost Horse Creek	June 14, 1898	39	160
Barnaby Creek	Oct. 17, 1898	302	480
Larry Creek	do.	257	280
Mill Creek	Mar. 9, 1903	2,993	4,249
Fred Burr Creek	Mar. 10, 1904	3,069	5,713
Sleeping Child Creek	Mar. 3, 1904	640	620
		8,230	12,855
Gallatin County			
E. Gallatin	Apr. 2, 1892	2,614	2,623
Missoula County			
Carlton Creek	Feb. 21, 1902	1,957	3,477
Rattlesnake Creek	July 9, 1903	1,803	3,869
		3,760	7,346
Sweet Grass County			
Bridger Creek	Mar. 18, 1898	455	880
Spring Creek	Nov. 17, 1899	300	320
Big Boulder River	Feb. 16, 1901	400	320
do.	Feb. 19, 1901	700	625
Duck Creek	do.	450	1,400
Otter Creek	June 25, 1903	675	1,440
Duck Creek	do.	2,386	6,032
		5,366	11,017

under permits from the State. It is thus obvious that by far the greater number of rights have been adjudicated by the courts. In adjudications of this character an essential feature is the placing of limitations on the maximum amount of water which can be used on an acre or on each parcel of land and such amounts represent the lowest duty. The wide influence exerted by some court decisions may be inferred from the following citation: In a decision rendered in 1910 by a judge of an Arizona court, the standard duty of water was fixed for much of the irrigated land in the Salt River Valley. The area affected by the decree embraced 179,970 acres and a constant flow of 48 miner's inches was allowed to each quarter section of land measured and delivered at the land. This is equivalent to one second-foot to each 133 1/3 acres or 5.42 acre-feet per

acre per annum. A standard transmission loss due to seepage and evaporation was also adopted. This loss was placed at 1 per cent of the flow per mile of main canal. Although of recent date, this decree has a far-reaching influence in that it has fixed for the past three years the duty of water for more than one-half of the irrigated lands of Arizona.

The liberal allotments of water granted by the courts of Montana are shown in the preceding table where 82,320 miner's inches have been decreed to irrigate 96,091 acres of land, or at the rate of one miner's inch (1/40 second-foot) to 1.17 acres.[3]

4. Water Right Contracts. Most contracts of this kind stipulate that the company which owns the canal system shall furnish water not exceeding a fixed maximum quantity which shall be applied to a definite area of land and in case of water shortage at any time, the amount available shall be pro-rated. A dry season, scanty water supply, faulty channels, lack of funds, or a large acreage to be served, afford ample opportunity to furnish excuses for delivering less than the stipulated maximum quantity. To illustrate the customary method of placing limitations on the quantity of water which can be used, as well as the usual provisions for pro-rating or delivering less than the maximum quantity, the following extracts from a water right contract in effect in Colorado are given:

"And it is expressly understood and agreed that a water right as sold and conveyed by this contract, is the right to use and enjoy in perpetuity, and during the irrigation season of each year, a sufficient quantity of water conveyed through the canals of the said party of the first part, (the company) to irrigate and to be applied upon the tract or parcel of land to which any such particular water right applies, but such quantity not to exceed one cubic foot of water per second of time for each eighty acres of land, the water to be delivered seasonably in such quantities within the limit mentioned as may be necessary for the production of crops, under skillful irrigation and cultivation, and in accordance with the rules and regulations of the party of the first part now prevailing or to be hereafter adopted. The irrigation season, within the meaning of this contract, shall begin between April 1st and May 1st of each year, according to climatic conditions, and shall continue to November 1st of each year, but water may be conveyed for domestic purposes whenever reasonably practicable in the opinion of said first party;

[3] Irrigation in Montana, Bulletin No. 172, O.E.S., U.S. Dept. of Agriculture, by the writer.

"It is further agreed that in case the party of the first part shall be unable to convey and distribute an amount of water equal to the maximum amount herein agreed to be furnished for each eighty acre water right, either from accident or from any lack of water in times of scarcity in the natural sources of supply, or other cause, it shall not be liable for the deficiency of supply so occasioned, nor for any loss or damage resulting therefrom, and it is also agreed that during such deficiency in the water supply, the party of the first part shall have the right to divide the diminished supply pro rata among the water rights outstanding and in use at such time from said canal and ditches, and for the purpose of so doing may establish and enforce such rules and regulations as it may deem necessary and expedient, and the party of the second part agrees in consideration of the premises, to waive, and does hereby waive any claim for loss or damage by reason of any leakage, seepage, breakage or overflow of the canals or laterals of the party of the first part and for any shortage of water as aforesaid."

Instead of agreeing to deliver a given volume of water in a continuous stream throughout the irrigation season, a company may agree to deliver periodically a maximum volume per acre during the season or during each calendar month of the season. In rather exceptional cases the company merely agrees to furnish sufficient water to produce crops.

FACTORS CAUSING VARIATION IN DUTY.

When the term "duty" is applied to a steam engine it is a measure of the number of foot pounds of work done per pound of fuel and the term is confined within a somewhat narrow range. On the contrary, when the same term is used to express the ratio between a unit of water and the land which it irrigates, the variation is great. This is chiefly due to the large number of physical and other conditions which tend to increase or diminish the amount of water applied. In briefly outlining the main causes of such a wide variation, the writer will not attempt to designate the order in which they should be placed, for the reason that the same causes may not always exert the same relative influence in all localities. Thus the large amount of water which porous soils usually require may be much lessened by the adoption of proper methods of application, and, again, the saving in water effected by a fertile soil may be wholly counterbalanced by the water requirements of the increased yield due to fertility.

(1) **Transmission Losses.** Reference has been made to the wide variation in the average duty of water on a canal system when determined by intake measurements and the average duty on the farms of the same system when determined by delivery measurements. Perhaps no other one factor causes so much variation in duty as transmission losses. These losses include absorption, percolation, evaporation, leakage through defective structures and illegal withdrawals along the routes of irrigation channels. The writer has estimated[4] that 95 per cent of such channels are unlined and that the losses in transmission from the source to the farms average 40 per cent of the total flow. There is a further loss in the small ditches which form the distributary system of each farm but this latter loss may be compensated in a measure by the utilization of return seepage water from various sources. The following table from Bulletin 126 of the U. S. Department of Agriculture, may convey some idea of the loss per mile in various channels:

Capacity of Canal Second Feet	Number of Tests	Average Loss per Mile Percent
Less than 1	16	25.7
1 to 5	37	20.2
5 to 10	30	11.7
10 to 25	49	12.1
25 to 50	48	5.5
50 to 75	31	4.3
75 to 100	26	2.7
100 to 200	45	1.8
200 to 800	27	1.2
800 and over	14	1.0

The remedy consists in the improvement of channels by lining or otherwise, but this in turn brings up the question of cost. It is, therefore, necessary in each case to weigh the cost of such improvements against the benefits to be derived in the form of water saved, greater carrying capacity, a lower charge for operation and maintenance and the less risk to crops.

(2) **Character of Soil and Sub-soil.** When soils containing a large percentage of sand, gravel or other porous material are irrigated it is difficult to prevent a large part of the water so applied from being drawn downward by natural forces to

[4] Concrete Lining as Applied to Irrigation Channels, Bul. 126, U.S.D.A.

depths beyond the root zone of plants. Furthermore, it is seldom that much of the water which escapes in this way can be restored to the root zone by capillarity, since this force acts only in a limited degree on water within the interstices of the coarse material. The capillary rise of soil moisture in a given time is usually less than one-third as great in coarse sand as it is in very fine sand. The readiness with which water percolates through coarse soils and the small and limited action of capillarity in recovering any part of the water so lost, make it necessary to apply more water to such soils. On the other hand, impervious soils, other conditions being equal, require less water. The results of a few experiments may serve to illustrate both conditions.

In 1910 the amount applied to an alfalfa field of very gravelly soil at Ketchum, Idaho,[5] was 21.3 acre-feet per acre and the yield was 3¼ tons per acre. In the same year the amount of water applied to the same kind of crop but on clay loam at Idaho Falls, was 1.41 acre-feet per acre and the yield was 5.04 tons per acre. Again, on the sand hill area north of the town of Hermiston, Oregon, forming part of the Umatilla Project of the U. S. Reclamation Service, the soil contains 60 to 90 per cent of coarse sand and gravel with little fine sand and an almost negligible amount of silt and clay. The irrigation season extends from March 16 to October 16,—210 days—during which period contracts call for the delivery to the land of 2.8 acre-feet of water per acre. In 1912 the actual average delivery to the entire project was 9.7 acre-feet per acre.

(3) **Value of Water.** For a long period after the first settlement of the fertile valleys of the West, water was abundant and little attention was paid to economy in its use. In some favored sections these conditions still prevail but they are rapidly becoming exceptional. The large number of uses to which water may be put in these modern times and the large investments which have been made in recent years in the development and utilization of water supplies, have increased the demand for water and this in turn has raised its value. In many cases the value of water has become a fairly reliable

[5] Report on Duty of Water by Don H. Bark, Biennial Report, Idaho State Engineer, 1911-1912.

index, not only of the available quantity but of the degree of economy practiced in its use. While water is still plentiful and cheap, less money is expended in providing proper facilities for its conveyance and application and the usual result is a large amount of waste and a correspondingly low duty.

(4) **Climate.** The effect of climate on duty of water is too well known to call for much comment. What is true of climatic conditions considered collectively is also true of such individual features as precipitation, temperature, evaporation, humidity, wind movement, and sunshine. Of these the amount and occurrence of the rainfall exert the greatest influence on duty of water. In humid and semi-humid regions, artificial supplies are said to be supplemental to the rainfall but in some respects the greater part of irrigation water supplements the natural supply. It is only in such localities as the Imperial Valley of California, the Tooele district of Utah and portions of Nevada, where the rainfall is a negligible quantity that this does not apply.

It is likewise true that the water derived from the clouds varies greatly in its efficiency. The cloud burst or violent rain storm may prove more detrimental than beneficial. Even the light shower may do harm by its speedy evaporation and the formation of a soil crust.

Aside from precipitation, the next most important influence exerted by climate consists in varying the length of the growing season and the duration of the irrigation period of each year. In the colder arid states the season is short and the application of water is confined to the summer months. In the warmer states of the Southwest irrigation may be required during the greater part of the year.

(5) **Preparation of Land.** The surface of each field of an irrigated farm should be carefully graded and smoothed so as to facilitate the distribution of water and the uniform moistening of all parts of the top layer of the soil. In addition to this preliminary work, there should be careful conservation of the soil moisture for such crops as require it. Failure to perform these necessary tasks through lack of means, labor or equipment, or through other causes, usually results in a low duty and small profits.

(6) **Diversified Farming.** The irrigation of small grains, such as wheat, barley and oats, requires large quantities of water for short periods each year. It therefore follows that when a farm or system is devoted mainly to the production of cereals and other crops which grow and mature about the same time, only a limited use can be made of the water supply. Such crops may require a large amount of water during the middle stages of growth and none thereafter. On the other hand, when such crops are diversified with forage, root and other crops which require late water, the use of water is extended over a longer period and in consequence irrigates a larger area. An exception to this is found in citrus orchards which have a long growing season and a proportionately long irrigation period in each year.

(7) **Time and Manner of Water Delivery.** While no rule can be laid down regarding either the time or manner of water delivery it is nevertheless true that both exert an influence on the duty of water. It is generally true that water, as well as labor and time, can be saved and an economical duty secured by using fairly large quantities of water for short periods of time. From the standpoint of economy in the use of water little can be said in favor of small continuous delivery heads. In the case of small holdings in particular, a proper system of time rotation is preferable.

(8) **Kind of Crops.** Although the proper percentage of soil moisture varies little for the standard crops, there is a wide variation in the water requirement of particular crops. This relative water requirement has been quite fully demonstrated recently and I present the following from the results secured:[6]

Crop	Variety	Pounds of water to one pound kiln-dried crop
Alfalfa	Grimm	834
Rice	Honduras	744
Potatoes	Irish Cobbler	659
Cotton	Triumph	657
Oats	Swedish Select	617
Wheat	Kubanka	496
Corn	Indian Flint	342
Millet	Kursh	286

[6] Journal of Agricultural Research, No. 1, Volume 3, by Messrs. Briggs and Shantz.

Some of the results of experiments having a like object in view, carried on under the supervision of the writer, give even greater differences between such crops as alfalfa, potatoes and wheat.

(9) **The Ground Water Level.** In irrigated districts a part of the water conveyed in earthen channels and applied to the soil in irrigation is apt to find its way by seepage to low tracts. When this occurs such tracts may become water-logged and when in this condition they do not require irrigation. In others the water level may rise to the margin of the root zone, in which case very little, if any, irrigation water may be needed. In comparing such conditions with a dry sub-soil, the influence of the ground water level is readily seen.

(10) **Fertility of the Soil.** Dr. Widtsoe, after conducting extensive and varied investigations on this subject, draws the following practical conclusion: "The irrigation farmer who wishes to make the best use of a limited quantity of water must keep steadily in mind the necessity of maintaining the soil constantly in a fertile condition."[7]

As the result of investigations carried on in Southern Idaho, Don H. Bark, of the Department of Agriculture, arrived at a similar conclusion. He found that the use of one acre-foot of water when applied to grain planted on alfalfa or clover sod, produced a larger yield than two acre-feet of water applied to grain planted on virgin soils.[8]

(11) **Methods of Applying Water.** Out of the large number of methods used in applying irrigation water to soil, it is usually possible to select one which is best adapted to the particular conditions of any given case. When the wrong method is introduced or when the water is carelessly applied under right methods, a low efficiency in water and reduced crop profits invariably result. The low efficiency arises from loss of water by deep percolation, uneven distribution, evaporation, run-off or any or all of these combined.

(12) **Manner of Paying for Water.** Wherever practicable, irrigation water should be measured out to users in the same way that water for domestic purposes is metered out to con-

[7] Principles of Irrigation Practice, by J. S. Widtsoe.

[8] Duty of Water, by Don H. Bark, Biennial Report, Idaho State Engineer, 1911-1912.

sumers, each paying for what he gets. Experiments have repeatedly shown that where water is delivered under a quantity rate, much smaller amounts are used at no sacrifice to the yields of crops.[9]

(13) **The Configuration of the Surface.** An even, uniform slope, neither too steep nor too flat, is one of the most favorable conditions for the economical use of water. Tracts that are traversed by ravines or other irregular formations are not only difficult to irrigate but the waste of water is usually considerable.[10]

(14) **Deficient or Fluctuating Supply.** A shortage of water necessitates either pro-rating the available flow or else shutting off the supply to those having inferior rights. In either case the duty of water is affected. The wide variation in the stream flow of the arid region likewise tends to establish the custom of using large quantities of water during periods of melting snow or heavy rainfall when the streams are bank full, and small quantities when there is a scanty run-off.

(15) **Statutory and Other Restrictions.** The effects of these upon duty of water have already been pointed out in the discussion of state laws, state control, court decisions, and water right contracts.

VARIATIONS IN DUTY.

As has been pointed out, there are so many factors and conditions which affect the duty of water in irrigation that wide variations in practice may be regarded as a natural sequence. Such variations are briefly discussed under the following headings.

(1) **Yearly Variation.** The duty varies more or less from year to year depending mainly on such physical conditions as the available supply, rainfall, kind of crops, and the like.

In this respect Middle Creek canal which waters part of the Gallatin Valley, Montana, may be regarded as typical of part of the Rocky Mountain region. This canal is the largest of thirteen ditches which divert water from Middle Creek, a tributary of the Gallatin River. During the five-year period,

[9] Use of Water in Irrigation, by the writer.

[10] Duty of Water in Montana, Bul. 43, Montana Experiment Station, by the writer.

from 1899 to 1903 inclusive, the writer and his assistants kept a continuous record of its flow and also determined the area of land which it served each season. The average annual duty, expressed in acre-feet per acre, is given below:[11]

Year	Acre-feet per acre
1899	2.10
1900	1.90
1901	2.33
1902	1.15
1903	1.48
Mean for five years	1.79

In Southern California, where much of the water is derived from wells, there is less fluctuation in the supply but annual variations occur there also as the result of climatic and other causes. This is shown in the duty record of one of the prominent canal systems of the citrus belt:

Period	Area Irrig'td. Acres	Water Used Ac. Ft.	Depth of Irrigation Water. Feet	Depth of Irrigation & Rainfall. Feet
Nov. 1, 1898 to Oct. 31, 1899	6996	15,682	2.24	2.72
Nov. 1, 1899 to Oct. 31, 1900	7502	16,695	2.23	2.67
Nov. 1, 1900 to Oct. 31, 1901	7502	14.968	2.00	2.67
Nov. 1, 1901 to Oct. 31, 1902	7870	16,885	2.15	2.62
Nov. 1, 1902 to Oct. 31, 1903	8080	14,904	1.84	2.93
Nov. 1, 1903 to Oct. 31, 1904	8387	19,292	2.30	2.76
Nov. 1, 1904 to Oct. 31, 1905	8500	15,294	1.80	3.16

(2) **Seasonal Variation.** Since by far the greater part of the work done in determining duty of water in this country is based on seasonal duty, the data which belong to this heading will be found under the heading "Results of Investigations."

(3) **Monthly Variation.** The monthly variation in duty is in the main due to the water requirement of crops during certain stages of growth and this in turn is controlled by climate. In the colder arid states there is a long cold period when plants are dormant, followed by a short warm period when plant growth is extraordinarily active. The growth of alfalfa, for example, in the Yellowstone Valley, Montana, is confined to less than 150 days in each year, while the same crop in the Imperial Valley of California grows more or less the year through. There is this further difference: The seasonal yield

[11] Irrigation in Montana, Bulletin 172, O.E.S., U. S. Dept. of Agri. by the writer.

per acre is greater in Montana than it is during any like period in California, other conditions being similar. It is thus evident that the growing period in the more northerly or more elevated parts of the West, coupled with the urgent demand for water during critical stages of growth, restrict the use of water to a few months of each year. This is shown in the monthly use of water in Idaho and Montana as compared with that in Southern California.

These tables not only show the monthly variation but also the seasonal requirement for diversified crops on average soils of both Idaho and Montana.

Summary of depths of water in feet, applied by months to 168 fields of grain and alfalfa on medium clay and sandy loam soils of Southern Idaho. Altitudes ranging from 2400 to 5000 feet.[12]

Crop	Season		April 1-15	April 16-30	May	June	July	Aug.	Sept. 1-15	Sept. 16-30	Total for Season
Grain	1910	39	.00	.00	.320	.645	.495	.095	.00	.00	1.556
Alfalfa	1910	17	.053	.018	.531	.720	.602	.551	.064	.00	2.540
Grain	1911	49	.000	.000	.021	.717	.428	.006	.000	.00	1.172
Alfalfa	1911	18	.000	.025	.525	.308	.945	.750	.190	.03	2.783
Grain	1912	34	.000	.00	.000	.914	.650	.059	.000	.00	1.623
Alfalfa	1912	11	.000	.00	.508	.443	.697	.474	.038	.00	2.160
Average			.009	.007	.318	.624	.636	.323	.050	.005	1.972
Percentage of Total			.46	.36	16.08	31.67	32.25	16.38	2.54	.25	100

Summary of depths of water in feet applied by months on porous, sandy and gravelly soils in Southern Idaho. Altitudes ranging from 2600 to 4825 feet.[12]

Season	No. plots	April 16-30	May	June	July	Aug.	Sept. 1-15	Sept. 16-30	Total for Season
30 fields of grain—									
1910	16	.00	.078	1.588	1.015	.411	.00	.00	3.093
1911	14	.00	.000	1.086	1.270	.732	.00	.00	3.088
Average		.00	.039	1.327	1.142	.572	.00	.00	3.090
Per cent of total			1.26	43.27	36.96	18.51			100
17 fields of alfalfa—									
1910	10	.372	1.723	1.610	1.743	1.680	.00	.00	7.130
1911	7	.280	.888	1.769	1.215	2.127	.219	.00	6.500
Average									
Per cent of total		4.78	19.16	24.80	21.70	27.94	1.62	.00	100
47 fields of grain and alfalfa—									
1910	16	.00	.078	1.588	1.015	.411	.00	.00	3.093
1910	10	.372	1.723	1.610	1.743	1.689	.00	.00	7.130
1911	14	.00	.00	1.086	1.270	.782	.00	.00	3.088
1911	7	.280	.888	1.769	1.215	2.127	.219	.00	6.500
Average		.163	.672	1.514	1.311	1.238	.055	.00	4.953
Per cent of total		3.29	13.57	30.57	26.47	24.99	1.11	.00	100

[12] Duty of Water, by Don H. Bark, Biennial Report, Idaho State Engineer, 1911-1912.

Monthly Duty of Water under Middle Creek Canal, Montana, for the years 1899, 1900, 1901, 1902 and 1903.[13]

Month	1899		1900		1901		1902		1903	
	Disch. Ac. Ft.	Depth Feet	Disch. Ac. Ft.	Depth Feet	Disch. Ac. Ft.	Depth Feet	Disch. Ac. Ft.	Depth Feet	Disch. Ac. Ft.	Depth Feet
May							263	.05		
June	1,539	.40	3,917	1.01	2,222	0.70	3,094	.64	2,898	.60
July	4,610	1.20	1,912	.50	2,973	.93	1,363	.28	1,515	.31
August	903	.23	1,075	.28	1,541	.48	857	.18	1,523	.32
Sept.	1,022	.27	420	.11	718	.22			1,201	.25
Total	8,074	2.10	7,324	1.90	7,454	2.33	5,577	1.15	7,137	1.48

Monthly Duty of Water under Republican Canal, Montana, for the years 1901, 1902 and 1903.

Month	1901		1902		1903	
	Discharge Acre-Feet	Depth Feet	Discharge Acre-Feet	Depth Feet	Discharge Acre-Feet	Depth Feet
April	1,608	0.39				
May	3,115	.76	3,442	0.71	3,043	0.63
June	2,116	.52	4,372	.90	3,852	.80
July	3,656	.89	3,995	.82	2,810	.58
August	3,263	.79	5,826	1.20	2,602	.54
September			4,251	.88	1,940	.40
Total	13,758	3.35	21,886	4.51	14,247	2.95

Monthly Duty of Water under Ward Canal, Montana, for the years 1901, 1902 and 1903.[13]

Month	1901		1902		1903	
	Discharge Acre-Feet	Depth Feet	Discharge Acre-Feet	Depth Feet	Discharge Acre-Feet	Depth Feet
April	591	0.16	230	0.06		
May	3,009	.84	2,318	.58	1,852	0.46
June	3,529	.71	3,752	.94	4,424	1.11
July	2,059	.57	2,566	.65	2,771	.70
August	438	.12	807	.20	844	.21
September			253	.06	345	.09
Total	8,626	2.40	9,926	2.49	10,236	2.57

Monthly Duty of Water under Riverside Water Company's system, California, 1901 to 1908, inclusive.[14]

Month	Average depth per acre Feet	Average rainfall Feet	Total water applied Feet	Month	Average depth per acre Feet	Average rainfall Feet	Total water applied Feet
December	0.159	0.109	0.268	July	0.272	0.002	0.274
January	.123	.170	.293	August	.269		.269
February	.046	.190	.236	September	.243	.015	.258
March	.078	.316	.394	October	.189	.043	.232
April	.177	.068	.245	November	.169	.073	.242
May	.291	.023	.314				
June	.274	.003	.277	Total	2.29	1.01	3.30

[13] Irrigation in Montana, Bul. 172, O. E. S. U. S. Dept. of Agri.

[14] Farmers' Bul. 404, U. S. Dept. of Agri., by the writer.

INVESTIGATING DUTY OF WATER.

The broad scope of duty of water in the United States was indicated in an introductory paragraph of this paper. Its investigation, which was begun nearly twenty-five years ago, was for years confined for the most part to the legal, administrative and engineering features. In more recent years greater consideration has been given to the agricultural and economic phases of the subject.

About a quarter of a century ago when the customs of the pioneer period of irrigation development were being crystallized into law and when corporations were expending large amounts of capital in the construction of irrigation works, the necessity for more accurate information pertaining to duty of water was keenly felt. Furthermore, so large a percentage of the diverted waters was being wasted that statutory enactments were passed limiting the use of water in irrigation to a fixed maximum quantity per acre.

In like manner, when a canal was designed and built, the acreage which its flow would serve could not be definitely determined for the reason that neither the duty nor the transmission losses were known. Similar guesswork had to be resorted to in framing water right contracts between a canal company and the water users under its system.

To remedy these uncertainties, and to provide reliable information on which to base estimates, records of the flow of typical streams and canals and measurements of the land which each served were obtained. These results proved useful to State officials in apportioning public water supplies, to courts in adjudicating water rights, to engineers in determining the capacities of irrigation channels, to canal managers in framing water right contracts, and to farmers in growing crops. The scope of these investigations was greatly extended when Congress, in 1898, granted funds to the U. S. Department of Agriculture for the purpose of investigating the subject of irrigation. As part of this work, which has been carried on for seventeen years, duty of water has always been given a prominent place. Of late years more attention has been paid to duty of water on individual fields and crops. Not content with ascertaining the amount applied to a given area, efforts have

been made to separate and measure the main sources of waste. In a large number of instances the losses sustained by deep percolation have been ascertained by borings and the taking of soil samples at different depths. The losses due to evaporation from irrigated soils have likewise been studied and measures recommended to lessen both causes of waste. So, too, the relation of water to plant growth has been investigated in both small and large units and in localities differing widely in soil. topography and climate.

RESULTS OF INVESTIGATIONS.

The limits of this paper will not permit the presentation of much of the valuable data which have been collected as a result of duty of water investigations. As an off-set to this limitation, care has been exercised in selecting from the mass of material available such records as would represent either typical or average conditions. The tabular information herein presented has also been grouped under three divisions. The first of these gives the average gross duty by streams and groups of canal systems, the second the average duty by canals, and the third the quantity of water in both irrigation and rainfall which the soil received in the production of a measured yield of the standard crops.

Gross Duty of Water by Streams or Groups of Canals.[15]

Stream	Approximate acreage irrigated	Water diverted per acre
California		
Little Shasta River	4,498	4.20
Feather River	17,935	7.24
Tuolumne River	135,317	3.00
Colorado River (Cal. side)	250,806	3.35
Santa Clara River	5,160	2.00
Tule River	5,000	4.94
Santa Ana River Valley	20,627	3.50
Colorado		
Big Thompson	32,000	1.80
Clear Creek	53,000	1.37
South Platte River	67,000	2.90
Montana		
Bitterroot	20,000	4.69
Nebraska		
North Platte	80,000	4.00
Utah		
Big Cottonwood	8,000	4.13
Logan	6,000	4.08
Washington		
Naches	15,000	4.86
Yakima	50,000	5.70
Wyoming		
Deer Creek		10.40
Horseshoe Creek		9.75

[15] Taken in part from Review of 10 Years of Irrigation Investigations, by R. P. Teele. Reprint of An. Rept. O. E. S., 1908.

Gross Duty of Water by Canal Systems.[16]

Canal	Approximate acreage irrigated	Water diverted per acre Ac. Feet
Arizona		
Salt River Project		
California		
Gage	9,040	1.83
Moore	7,000	3.15
McNally	7,000	2.69
Sutter-Butte Canal Co.	14,000	7.53
Miller & Lux canals	55,700	2.46
San Joaquin and King's River	163,350	2.75
Bear Valley Mutual Water Co.	15,000	2.00
Santa Ana Valley canal	17,000	1.91
Imperial Water Co. No. 1	100,681	3.35
Colorado		
Amity	31,870	3.02
Lake	15,000	2.58
Grand Valley	40,000	3.50
New Cache la Poudre	30,000	2.21
Supply	7,000	1.79
Colorado	52,850	1.61
Idaho		
Riverside	6,898	9.48
Farmers' Cooperative	13,062	4.73
Settlers	11,755	2.86
Ridenbaugh	30,973	3.19
South Side Twin Falls	147,309	4.68
Montana		
Huntley project	15,796	2.30
Sun River project	7,500	3.29
Big Ditch	25,000	2.71
Nevada		
Orr Ditch	6,000	7.08
Truckee Carson project	36,620	4.70
New Mexico		
Pecos	8,500	7.90
Utah		
Logan-Hyde Park and Smithfield	3,182	5.42
Logan and Richmond	3,374	5.16
Bothwell or Bear River	34,778	3.45
East Jordan	16,000	2.54
Washington		
Sunnyside project	64,400	5.00
Wenatchee Valley	12,000	2.70
Tieton project	18,750	3.20
Cascade	7,000	2.50
Kennewick	14,000	4.70
Wyoming		
Wyoming Development Co.	34,548	2.93

[16] Taken in part from Review of 10 Years of Irrigation Investigations, by R. P. Teele. Reprint of An. Rept. O. E. S., 1908.

Amount of water in both irrigation and rainfall received by the soil, and the corresponding yield.

Alfalfa.

Location	Amt. irrig. water applied Feet	Rainfall Inches	Yield	Reference
Pomona, Cal.	2.30	9.1	5-9 tons	F. B. 373
Gridley, Cal., 1913	2.55	13.92	5.84 "	F. Adams
" " "	2.37	13.92	5.97 "	"
Los Molinos, Cal.	4.91	13.92	3.02 "	"
" " "	4.46	13.92	3.78 "	"
Orland, Cal., 1913	2.83	9.84	4.44 "	"
" " "	3.07	7.32	7.49 "	"
Dixon, Cal., 1913 Av.	2.92	7.32	6.04 "	"
Los Molinos, Cal., 1914	2.34	32.88	5.78 "	"
" " " "	1.42	32.88	4.44 "	"
" " " "	5.47	32.88	5.68 "	"
" " " "	6.08	32.99	6.68 "	"
Orland, Cal., 1914	5.04	28.68	5.49 "	"
" " "	9.59	28.68	5.84 "	"
Woodland, Cal., 1914	2.91	29.40	6.96 "	"
" " "	2.14	29.40	8.07 "	"
" " "	1.00	29.40	5.56 "	"
Bozeman, Mont.	1.00	8.40	4.42 "	F. B. 373
" "	2.50	8.40	7.20 "	"
So. Idaho, 1910	1.87	1.85	3.56 "	D. H. Bark
" " "	6.92	2.36	3.65 "	"
" " "	2.65	2.23	4.28 "	"
" " 1911	2.33	5.35	5.57 "	"
" " "	6.40	6.95	3.42 "	"
" " 1912	2.07	3.71	5.84 "	"
" " "	2.96	8.25	4.11 "	"
Utah Station, 1912	.83		4.94 "	Sta. Bul. 117
" " "	1.66		4.59 "	" " "
" " "	2.08		4.67 "	" " "
" " "	4.17		5.41 "	" " "

Sugar Beets.

Location	Amt. irrig. water applied Feet	Rainfall Inches	Yield	Reference
Loveland, Colo.	1.35		17.45 tons	F. B. 392
Utah Station, 1904	1.12		9.85 "	Sta. Bul. 80
" " "	1.22		18.40 "	" " "
" " "	1.49		17.14 "	" " "
" " "	1.67		21.99 "	" " "
" " "	4.41		13.20 "	" " "
Utah Station, 1912	0.42		13.78 "	Sta. Bul. 117
" " "	1.25		19.45 "	" " "
" " "	2.50		20.82 "	" " "
" " "	4.17		24.54 "	" " "

Wheat.

Location	Amt. irrig. water applied Feet	Rainfall Inches	Yield	Reference
So. Idaho, 1910	1.44		67.2 bu.	D. H. Bark
" " 1911	1.62	5.35	33.8 "	"
" " 1913	1.31	7.35	23.83 "	"
N. M. Exp. Sta., 1904	2.94		18.00 "	Bul. 158 O.E.S.
" " " "	2.43		16.5 "	" " "
" " " "	1.50		10.6 "	" " "

Wheat—Continued.

Location	Amt. irrig. water applied Feet	Rainfall Inches	Yield	Reference
Utah Station, 1901	.38		4.5 "	Sta. Bul. 80
" " "	.86		14.66 "	" " "
" " "	1.75		17.33 "	" " "
" " "	2.50		26.66 "	" " "
" " "	3.35		14.50 "	" " "
" " 1912	.42	13.74	37.81 "	Sta. Bul. 117
" " "	.83	13.74	43.53 "	" " "
" " "	2.93	13.74	48.55 "	" " "
" " "	4.16	13.74	49.38 "	" " "

Oats.

So. Idaho, 1910	2.20	1.49	27.7 bu.	D. H. Bark
" " 1911	1.32	5.80	73.5 "	"
" " 1913	1.28	7.35	44.88 "	"
Utah Station, 1901	.58		12.50 "	Sta. Bul. 80
" " "	1.16		40.62 "	" " "
" " "	2.50		85.00 "	" " "
" " "	3.35		80.00 "	" " "
" " 1912	.42	9.66	62.28 "	Sta. Bul. 117
" " "	1.25	9.66	71.54 "	" " "
" " "	1.66	9.66	80.70 "	" " "
" " "	3.75	9.66	79.06 "	" " "

Barley.

Utah Station, 1912	.63	9.66	68.76 bu.	Sta. Bul. 117
" " "	1.25	9.66	67.66 "	" " "
" " "	3.29	9.66	62.59 "	" " "
Wyoming Sta., 1908	.70		6.31 "	Sta. Bul. 77
" " "	1.63		35.32 "	" " "
" " "	2.19		20.96 "	" " "
" " "	2.89		30.58 "	" " "

Potatoes.

So. Idaho	0.88	1.85	6,302 lbs.	D. H. Bark
" "	1.50	1.85	11,932 "	"
" "	1.94	3.47	18,613 "	"
" "	2.21	3.98	16,738 "	"
" "	2.53	3.47	16,681 "	"
" "	2.83	6.95	12,708 "	"
" "	3.64	3.98	16,754 "	"
Utah Station, 1901	0.67		9,559 "	Sta. Bul. 80
" " "	1.25		9,920 "	" " "
" " "	2.25		21,760 "	" " "
" " "	3.35		31,680 "	" " "

Orchards.

Riverside, Cal.	2.29 [17]	12.12		F. B. 404

[17] Average for irrigation system.

WATER REQUIREMENT OF CROPS.

Water used for irrigation purposes has a low efficiency. This is mainly due to the large percentage of waste. Out of every three gallons taken from a stream it is probable that on an average only one gallon is put to a beneficial use in nourishing plants. The remainder is wasted in transmission, deep percolation, run-off, and evaporation. As a rule the efficiency of water used to generate power is much greater than when water is used to irrigate land. In the case of the former, from 17 to 20 per cent of the total energy in the water is lost by the water wheel, the generator may lose 7 per cent of the remainder, the two transformers 6 per cent and the transmission line anywhere from 5 to 35 per cent. But after all these losses are deducted the efficiency of water for power is still about double that for irrigation.

No good reason can be given for this wide difference. It is entirely feasible to convey water for irrigation purposes at a much smaller loss than a copper wire transmits energy and it is also feasible to prevent all run-off from the irrigated field. There remain only the losses from deep percolation and evaporation and both of these can be reduced to a small percentage of the total quantity used, by the exercise of intelligence and care.

In the light of the foregoing and in order to bring about a more economical use of irrigation water, efforts have been made to determine the actual amount of water required for various crops. To do this it is necessary to eliminate, as far as practicable, all losses of water. Regardless of how much water may be applied to the soil, only that part which is utilized by the plant is considered. This may be termed the maximum duty of water, since it represents the least amount which will produce a given yield. This maximum duty or the actual water requirement of crops is usually expressed in pounds of water absorbed to one pound of dry crop produced. In the determination of this ratio it may be well to state that well-nigh insurmountable difficulties present themselves. In order to ascertain the amount of water absorbed by a given number of plants it is necessary to grow the plants in soil placed within

vessels. This is very difficult to accomplish if natural conditions are maintained at the same time. On the other hand it is comparatively easy to obtain relative results by growing different kinds of plants under more or less artificial conditions and then comparing their duty of water ratios. The most extensive experiments of this character have recently been completed by the U. S. Department of Agriculture and the following table gives a summary of the results.[18] The figures refer to the relative number of units of water required to produce a similar unit of crop kiln-dried at a temperature of 110 degrees Centigrade. Thus, for example, an average of 513 pounds of water is shown to have been required to produce one pound of kiln-dried wheat and straw, exclusive of roots.

Summary of water-requirement determinations at Akron, Colo., 1911, 1912 and 1913, based on the production of dry matter.

Crop	Mean water requirement of different varieties
Millet	310
Sorghum	322
Corn	368
Wheat	513
Barley	534
Buckwheat	578
Oats	597
Sugar Beets	397
Potatoes	636
Cotton	646
Cow-pea	571
Soy Bean	744
Sweet Clover	770
Canada Field Pea	788
Purple Vetch	794
Crimson Clover	797
Alfalfa	831

The foregoing results possess a high value to the dry farmer who can estimate, by test boring and sampling, the amount of moisture in the soil. He can also estimate with some degree of accuracy the additional moisture to be derived by rainfall during the growing season. These being the only sources of supply of available moisture it is important for him

[18] Relative Water Requirement of Plants, by Briggs and Shantz, Journal of Agricultural Research, No. 1, Volume III.

to know which crop requires the most and which the least water, so that he may plant crops which will best suit the moisture condition of his field.

In the case of irrigated crops, a supplemental supply of water is available and under the control of the farmer. It is, therefore, seldom that he is called upon to grow millet or corn because there is not sufficient moisture to grow alfalfa. His problem is to ascertain the actual water requirements of crops under normal conditions and to make use of this information as a basis for arriving at an economical duty of water. In other words, he wishes to ascertain the actual rather than the relative water requirement of the most profitable crops grown on his farm.

As a result of studying this subject from the standpoint of the irrigator, the writer has adopted equipment and methods which, though rather costly and clumsy, secure results closely akin to those obtained under field conditions. The pots used by Briggs and Shantz held 254 pounds of soil (115 kg.). The tanks used by the writer held on an average about 1,250 pounds. In comparing the results of medium-sized tanks holding 300 to 400 pounds of soil with larger tanks holding 1,000 to 1,500 pounds (454 to 673 kg.) it was found that less water was required to produce a pound of dry crop when grown in large tanks. This led to the adoption of a standard tank which weighed approximately 1,000 pounds when filled with light moist soil and 1,500 pounds when filled with heavy moist soil.

The writer likewise began experimenting with single tanks but later discarded these for double water-jacketed tanks. In the case of single tanks it was found impossible to control the temperature. As a rule the temperature of the soil in the tank was much higher than that of the adjacent soil in the field and this not only affected the crop but also its water requirement. In using double tanks with the annular space between filled with water it is possible to maintain the temperature of the soil in the inner tank practically equal to that of the adjacent soil. These double tanks are installed in the open with the outer tank placed in such a way that its top is slightly raised above the surface of the ground. The inner tank is usually provided with a false bottom through which

Fig. 1. Layout of Experimental Tanks, Duty of Water Investigations, with Derrick, Windlass and Scales.

Fig. 2. Alfalfa Crop in Water-jacketed Experimental Tank.

drainage water can be withdrawn. When filled with soil it is placed within the outer tank and the annular space is filled with water. By means of a derrick it is periodically raised by a bail, placed on a scale, weighed, and then returned to its former position. Figures 1 and 2 illustrate the equipment used.

The methods followed can be best shown perhaps by a brief reference to tank experiments with alfalfa at Davis, California, during the summer of 1912, under the supervision of Professor S. H. Beckett of the University of California. The alfalfa was seeded in March, 1911, and four cuttings were

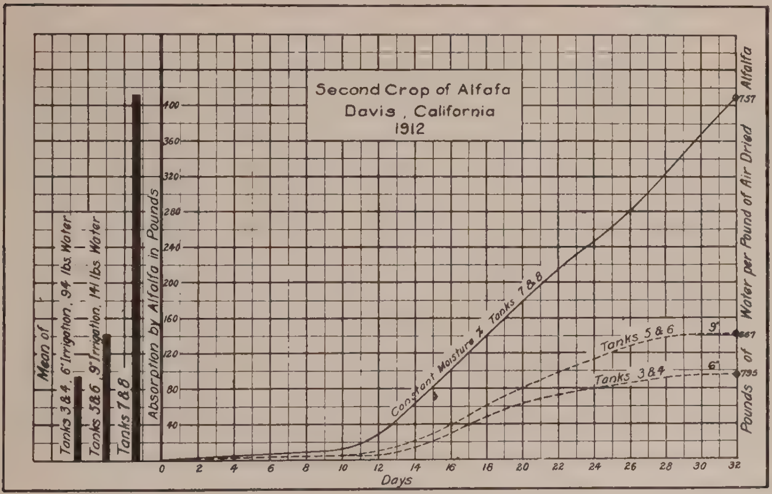

Fig. 3.

obtained. According to the schedule, tanks 1 and 2 were to be bare soil, the alfalfa in tanks 3 and 4 was to receive a small quantity of water, that in tanks 5 and 6 a larger quantity, while that in tanks 7 and 8 was to be maintained at a constant moisture content throughout the growing period.

The accompanying diagram, Fig. 3, shows the amounts of water applied after the first cutting in 1912 in order to produce the second cutting in the three sets of tanks and also the quantity of water absorbed by the plants in pounds during the thirty-two days of growth. The corresponding water requirement ratios are as follows:

Mean of tanks 3 and 4	795
" 4 and 6	667
" 7 and 8	757

The seasonal records for 1912 were:

Cutting	Water per pound of dry alfalfa
1st	522 pounds
2nd	740 "
3rd	720 "
4th	862 "

DUTY OF WATER IN RELATION TO FUTURE DEVELOPMENT IN IRRIGATION.

According to the last census the average gross duty of water in the United States in 1910 was 4.75 acre-feet per acre. From the same authority it is learned that 35 per cent of the land irrigated in 1909 was under rights that had been adjudicated by the courts. When compared with other agencies employed to adjudicate water rights, the courts may be said to grant liberal quantities of water per unit of land irrigated. In the light of the foregoing statements it may be stated that if the service which irrigation water now performs is to continue and if such use is to be confirmed by court decrees, it is doubtful if there is sufficient water available in the seventeen Western States to irrigate more than 50,000,000 acres. The extent of arable land susceptible of irrigation throughout these seventeen states is not accurately known but it may be safely estimated at 350,-000,000 acres. After deducting the 50,000,000 acres which, according to the estimate, can be irrigated, there remain 300,-000,000 acres of arable land which must be either pastured or dry farmed throughout all future ages. It is a well known fact that the revenues derived from pastured or dry farmed lands are small in comparison with those derived from lands intensively cultivated and irrigated. It therefore appears that the future agricultural development of this group of states depends in no small degree on the care exercised in allotting and using the limited water supplies in the most economical manner possible.

This need is further shown in the case of California. As one of the results of a survey carried on jointly by the Irriga-

tion Investigations of the U. S. Department of Agriculture and the Conservation Commission of California it was found that the State contained considerably more than twice as much fertile arable land as there was water to irrigate it. One of the conclusions reached by Mr. Frank Adams who was in charge of this cooperative work is as follows:[19]

"The total area of irrigable agricultural land found in the zones of irrigation water supplies, which include all of the valley lands, the rolling plains of the Great Valley, the arable portions of the Sierra foothills up to about 3,000 feet in elevation, and all of the plateau and desert lands to which some irrigation water supplies are available, is 21,865,200 acres, of which 3,192,646 acres are already irrigated, and 9,699,600 acres are estimated as the area to be ultimately irrigated.

"While these studies have not yet progressed far enough to give final data, they already show that the best economy demands limiting the quantity the State should allow, in so far as the State has authority to check excessive use, not to the quantities irrigated soils can absorb, but to the quantities irrigated crops can use. Speaking in the interest of the public which in the end is paramount, "beneficial" use in irrigation can be only considered use that helps plants to grow and produce. Only a realization and an enforcement of this principle can bring about the irrigation of the nearly 10,000.000 acres of California agricultural lands that it is estimated in this report may ultimately be watered."

DISCUSSION

Mr. Means.

Mr. Thomas H. Means,* M. Am. Soc. C. E. (verbally), stated that he had been interested most in the amount of water retained by the soil. As the result of this investigation it has been found that not over one third of the water diverted from the river is actually used by the plant growths; and it is considered that much better efficiency can be secured. The average farmer knows little as to what actually happens to the water after it is applied to the land and in this respect a wide field of investigation is open both to the Experiment Stations and to engineers. The sooner voluminous information on this subject is collected, the sooner it will be possible to solve problems of the duty of water in irrigation.

[19] Bulletin 254, O. E. S., U. S. Dept. of Agri.

* Civ. Engr., San Francisco, Calif.

Mr. Lee. **Mr. C. H. Lee,*** Assoc. M. Am. Soc. C. E. (verbally) stated, referring to the large amount of water lost in the soil by deep percolation, that some measurements made by him in New Mexico confirm the fact of such losses. An alfalfa field was divided into several parts—one part being irrigated by the method generally used by the owner, and the other parts being given both greater and less amounts of water. Before the first cutting of alfalfa, the owner used 5½ feet depth of water, allowing the flow to continue day and night. Various smaller amounts of water were used on other parts of the land, with the result that for the first two cuttings two 6-inch irrigations gave alfalfa yields twice as large as those produced by the owner's practice. These smaller irrigations were accomplished by using large heads which covered the land rapidly. The temperature of the water had a very noticeable effect in these experiments. The water was received at a temperature of 46° Fahr. and evidently cooled the soil to great depths, and when excessive amounts of water were used checked the growth of the alfalfa. The smaller depths of water did not cool the soil so much and the alfalfa recovered more quickly. The effect of the temperature of the water also is illustrated in the Owens River Valley, where in the west side the crops on lands irrigated from cold mountain streams generally are two or three weeks slower in starting than those on the east side, which are irrigated from the warmer water of the Owens River.

Much progress has been made within the last fifteen years in improving the duty of water for irrigation. Some of the data presented in the author's paper are old and Mr. Lee believes should be used with caution. For instance, the author gives the duty for 500 acres in the Pecos Valley, New Mexico, as 7.9 acre-feet per acre per year. Probably this land is within the Carlsbad Project, which now has a gross duty of 5½ acre-feet per acre per year and a net duty of 2½ acre-feet; so that the figures given by the author represent former conditions rather than present practice. Investigations in the Owens River Valley have shown that some farmers are using 16½ acre-feet per acre per year, while adjacent farmers are securing equivalent results with only 7 acre-feet.

The question of the effect of the size of pan upon evaporation records has been mentioned. The location of such evaporation pans, whether in dry or wet soils, also is important. The annual evaporation from a pan floating in water is about equal to that from a deep pan embedded in moist soil. A pan embedded in dry soil will lose about one third more than a pan in moist soil. In comparing pans in soil with those in water, the records should not be used comparatively if the soil pan is located in dry soil.

Mr. Duryea. **Mr. Edwin Duryea, Jr.,**† M. Am. Soc. C. E. (verbally), revised and amplified by letter), referring to the subject of evaporation just mentioned, stated that he is one of the authors of a long paper on evapora-

* Civ. and Hydr. Engr., Los Angeles, Calif.

† Cons. Engr., San Francisco, Calif.

Mr. Duryea.

tion losses from reservoirs, published in the Proceedings of the American Society of Civil Engineers for September, 1915. The paper referred to treats of the determination of the yearly evaporation depth from a large reservoir, in an instance where it was of unusual importance to ascertain a safe and reasonably accurate value, where there were no existing evaporation data for places nearer than 300 miles, and no local data except mean temperatures and elevation above sea-level. It treats also of the checking of the depths thus estimated, by local evaporation observations started for that purpose and by inflows and outflows of the lake. The reservoir referred to is Lake Conchos, in Mexico, about 300 miles south of El Paso, Texas.

The yearly evaporation depth from the lake was estimated by three methods, with results varying from 52.4 to 59.3 inches per year. The first method (using as data observed evaporations in land and floating pans in Texas and New Mexico, and observed mean temperatures and known elevations at the evaporation points in Texas and New Mexico and at Lake Conchos) gave 52.5 inches as a yearly evaporation depth at Lake Conchos. The second method (using in addition five months' observed pan-evaporations at Lake Conchos) gave an annual evaporation depth of 53.7 inches. The third method (making use of estimated inflows and outflows from the lake for seven months) gave 59.3 inches evaporation per year, without deducting known but partly unmeasured losses by absorption and seepage. At the end of two months' observations of local pan evaporations and four months' observations of lake evaporations, 55 inches was adopted as a yearly evaporation-loss from Lake Conchos; and at the end of five months of pan evaporations and seven months of lake evaporations, the same value (55 inches) was re-adopted. Lake Conchos is on the "Great Plateau" to the east of the western Sierra Madre range, has an elevation of about 4300 feet above sea-level, and a mean yearly temperature of about 67° Fahr.

In addition to estimating the yearly evaporation-depth from Lake Conchos, the paper states also the following relative evaporation depths from land and from floating pans and from reservoirs, these values being based on the author's interpretation of an equation of Prof. Frank H. Bigelow (of the U. S. Weather Bureau) derived in connection with his Salton Sea evaporation experiments of 1910:

(a) Evaporation depth from a 2-ft. square pan	=	about	108%	of	that	from	a	3-ft.	square	pan.
Evaporation depth from a 2½-ft. square pan	=	"	104%	"	"	"	"	3 "	"	"
Evaporation depth from a 3-ft. square pan	=	"	100%	"	"	"	"	3 "	"	"
Evaporation depth from a 4-ft. square pan	=	"	93%	"	"	"	"	3 "	"	"
Evaporation depth from a 5-ft. square pan	=	"	86%	"	"	"	"	3 "	"	"
Evaporation depth from a 6-ft. square pan	=	"	80%	"	"	"	"	3 "	"	"

Mr. Duryea.

(b) Evaporation depth from a floating pan	= about 80% of that from a land-pan of the same size.
(c) Evaporation depth from a large reservoir	= about 62% of that from a 3-ft. square pan floating thereon.

In the discussions (as yet uncompleted) of the Lake Conchos evaporation paper, some of the above values are contested.

Other conclusions of the evaporation paper referred to, as to the relation (d) between evaporation depth and mean temperature, and as to the relation (e) between sea and evaporation depth and elevation above sea, are as follows:

(d) In the Great Plateau Region, and at elevations above sea level of 3000 to 5000 ft. and for monthly evaporation losses (from 3-ft. square floating pans) of 2 to 10 in. the increases in the evaporation depth are nearly in direct proportion to the increases in the mean monthly temperature: but at lower elevations (3000 to 600 ft.) the evaporation depth increases with the mean temperature, but much less rapidly than in direct proportion.

(e) In the Great Plateau Region, and at elevations above sea-level of 600 to 5000 ft. and for monthly mean temperatures higher than 70° Fahr., the increases in the evaporation depth at any given mean temperature are directly proportional to the increases in elevation; but at monthly mean temperatures lower than 70° Fahr., and at the lower elevations, the evaporation depth at any given mean temperature increases with the increase in elevation, but less rapidly than in direct proportion.

Referring to the duty of water in irrigation, Mr. Duryea stated as follows:

As an average for the lands in such irrigation districts as the Modesto, Turlock and South San Joaquin in the San Joaquin Valley, California, the advisable number of irrigations is believed to be six per year, which, combined with a depth of 4 to 6 inches per irrigation, is equivalent to a depth per year on the net area irrigated of from 2 to 3 ft., measured on the land. As the result of all his study in connection with the design of the South San Joaquin irrigation system, he decided that the proper average depth for the irrigation of alfalfa is 4.5 in. per month, or 2.25 ft. per year, measured on the net area irrigated.

To provide for a possible "peak use" of the water, and to meet demands for a very ample supply, the supply canal and the main distributary canal of the South San Joaquin system were proportioned to deliver 6 in. net water per month on the net area to be irrigated, after all probable losses from absorption and seepage, and without encroachment on the safe "free-board" of the canal banks; and, to provide for "rotation", the branch canals were proportioned to deliver the 6 in. each month when in use only about two thirds of the full time, and the district ditches when in use only a few days during the month.

The 4.5 in. per month or the 2.25 ft. per year, measured on the net area, are for alfalfa alone. Hardly any other crop requires as much water, and in nearly all large irrigated districts a considerable and increasing proportion of the total area is in other crops. Hence in Mr. Duryea's opinion, the advisable average use of water in such large irri-

Mr. Duryea.

gation districts should be materially less than 2.25 acre-ft. per year per acre of net area. This is as measured on the lands irrigated that year, presumably about 80% of the gross area of the irrigation district; referred to the gross area, the advisable depth would be materially less than $(2.25 \times 0.80 =)$ 1.80 ft. per year.

Of course to supply these net depths of water on the lands to be irrigated, enough additional water must be diverted from the river into the headworks of the system to provide for all absorption and seepage losses from the canals, between the river and the irrigated lands. In the design of the South San Joaquin irrigation system, it was concluded that 36%, at most, of the water diverted from the river might be lost by absorption and seepage from the canals and ditches (that part lost from the distribution system tending to supply sub-surface irrigation more or less, however, and hence being only a partial loss) and that 64% or more would be available for the direct surface irrigation of the land. Under this supposition, the corresponding depth measured at the diversion point would be (less than 1.80 ft. ÷ more than 0.64 =) somewhat less than 2.81 ft.

Although realizing that most irrigators will dissent from this conclusion, it is Mr. Duryea's judgment that for such irrigation districts as are under discussion (where it is very desirable to keep the ground-water at least 6 ft. below the ground surface and usually difficult to do so on a large proportion of the district), an average irrigation depth of 2.5 ft. per year, referred to the gross area and measured at the diversion from the river, is advisable and not unreasonably low, and is sufficient to furnish adequate irrigation to lands which have been checked with reasonable skill and care, and when irrigated with reasonable skill.

The gross area of the South San Joaquin Irrigation District is 71,050 acres. In Mr. Duryea's judgment, the necessary and advisable water supply is about 600 cu. ft. per sec., as measured at the diversion point from the river, or about 480 cu. ft. per sec., as measured at the edge of the District lands. Expressed in this way, the corresponding advisable "duties" of the water are about 118 and 148 acres per cu. ft. per sec., respectively.

To permit of building up reservoir storage, even while irrigating, the headworks, the canals, and the tunnels above the reservoir site were proportioned for much greater flows; and to permit of a possible "peak use" of the water and to meet desires for an ample water supply, the canal below the reservoir was proportioned to deliver 650 cu. ft. per sec. at the edge of the District, corresponding to a "duty" of about 110 acres per cu. ft. per sec. The gate outlets from the branch canals and district ditches are proportioned to deliver water on the lands at a duty of 134 acres (gross area) per cu. ft. per sec.

Mr. Duryea is informed by a skillful irrigator of the South San Joaquin District that (on land prepared with reasonable care by "border" or "strip" checking) he is able to irrigate alfalfa adequately on sandy land with a "head" of 16⅔ cu. ft. per sec., at the rate of 20

Mr. Duryea. min. or somewhat less per acre. That head flowing for 16⅓ min. is equivalent to 4.5 in. of water on the net area.

Mr. Griffin. **Mr. A. Griffin,*** Assoc. M. Am. Soc. C. E. (verbally), stated that studies of the duty of water are most applicable and valuable in the locality in which the data are secured. The amounts of water needed for lands vary in different parts of the same project; for instance, in the South San Joaquin Irrigation District (of which he is now the Chief Engineer and Superintendent) a portion of the lands in the lower end of the District is water-logged at present, while at the higher end of the District the lands require irrigation. On sandy soils, sub-irrigated lands give the best results from irrigation. Both for design and operation, more data should be accumulated on the question of the monthly variation in the use of water for irrigation. In the San Joaquin Valley the main difficulty is to supply the desired amounts of water for use from August to November, and larger amounts of water would be used then if more water were available. However, enough water cannot be secured during these months from natural streamflow, but only by making use of stored waters.

The amount of water required per season or year for irrigation varies in different years. When the spring rainfall is more than normal, the first irrigation is delayed. In normal years about 14 to 15% of the total annual use of water occurs in June and July, the amount used in May is less, and the amount used in August and September decidedly less. Also, the percentages are affected by the kind of crops which are raised; where a large part of the land is in one crop, the use tends to occur in a series of peak-loads, which makes operation difficult; then it is impracticable to supply all of the lands with their full water-supply within a short period of time, and thus some damage may result where all of the land is in one crop. In such cases a regulating reservoir near the lands may be of great assistance.

Mr. Norboe. **Mr. P. M. Norboe,†** M. Am. Soc. C. E. (verbally), called attention to the pending publication of results of experiments at Davis, California, on the duty of water, stating that these data are included in the last report of the State Engineer of California. The actual use of water at Davis does not indicate the proper use or amount in other localities, but the general laws developed there will hold elsewhere.

It is desirable that similar experiments on the duty of water be made in other localities, and that farmers be informed of the results, so that they may obtain the best crop results from their irrigation practice. The question of seasonal use also is important. It may be determined that 3 acre-feet per acre per year is necessary, but the distribution of this yearly amount to the various months is equally important.

Mr. Hillebrand. **Mr. W. A. Hillebrand,‡** (verbally) stated that in 1914 the Pacific Gas & Electric Company made many tests on isolated pumping plants, to about one thousand of which they now supply power. The results

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† Asst. State Engr., Sacramento, Calif.

‡ Pacific Gas & Electric Co., San Francisco, Calif.

Mr. Hillebrand.

obtained from these tests probably will be of much use in determining seasonal and monthly duties of water. Efficiency tests were made on 450 pumping plants, which, with the records of the power used and the known discharges of the pumps, enable the average amount of water used each month to be computed. It was found that in the neighborhood of San Jose, Santa Clara Co., Calif., where the principal crop is fruit, about 12 inches depth of water per year is used, or a total, including the rainfall, of about 30 inches. The amount is affected, however, by the matter of the rainfall—whether distributed or in a few heavy storms. In Solano Co., Calif., where the principal crop is alfalfa, the monthly distribution to the months of the seasonal or yearly irrigation water-supply is very different from that in Santa Clara County.

Prof. Marx.

Prof. C. D. Marx,* President Am. Soc. C. E. (verbally) stated that it is impracticable to define a general duty of water for all cases. In the end, the irrigator is the sole judge and there will have to be a large diversity in the duties depending on the diverse conditions. However, it is practicable to define the legitimate duty of water for irrigation in any one locality and if the waste of water is to be stopped, this must be done. However, it is not practicable to embody such results in legislation.

Mr. Grunsky.

Mr. C. E. Grunsky,† M. Am. Soc. C. E. (by letter), stated that as Dr. Fortier has pointed out, a clear distinction should be made between the gross duty and the net duty of water. The larger the relative loss of water from the canals and ditches in transit from the source of the water (the point of diversion from the river) to the field, the greater will be the difference between the gross duty and the net duty.

The author says there is perhaps no other factor which causes so much variation in duty as the transmission losses. How true this is can be seen readily if a canal system be considered in which the flow during the irrigation ordinarily is any amount such as 100 cu. ft. per sec., with transmission losses of about 50%. Should this same canal system be brought into service with an average flow of 50 cu. ft. per sec. and only an occasional maximum flow in excess of 100 cu. ft. per sec., the canal and ditch losses would remain near 50 cu. ft. per sec.—except for the fact that the smaller discharge would compel a reduction of the mileage of canals and ditches in use at the same time. In consequence, the proportional amount of water lost would appear much larger, even though the rate of loss per mile of canal or per square foot of water-surface might remain almost unchanged. For this reason, such information as that presented by the author in the paragraph on "Transmission Losses" must be used with caution.

Transmission losses can be expressed more satisfactorily in units of canal water surface or (what is nearly the same) in units of the wetted canal-bed than in terms of percentage of the canal flow. It has become customary to refer seepage losses to the wetted canal-bed. It would be better to use the water surface, because the seepage is more

* Prof. Civ. Engrg., Stanford University, Calif.

† Cons. Engr., San Francisco, Calif.

Mr. Grunsky. nearly proportional to the horizontal soil area into which gravitation forces the water, than to the area of the inclined surfaces which go to make up the wetted canal-bed. Ordinarily the seepage is affected more by the rate at which gravitation draws the water downward to a union with the ground-water, than by the effect of capillary attraction. Furthermore, the increment of loss due to evaporation is proportional to the water surface and not to the wetted area of the canal-bed. Usually, however, there is not enough variation in the relation between water surface width and wetted perimeter to affect the results seriously, and the time may not have come yet to insist upon a change from the established custom.

Mr. Grunsky at various times has had occasion to express an opinion upon the probable loss of water from canal and canal systems, or to satisfy himself of the amounts of such loss. Experiments made by him over 30 years ago for the State Engineer of California,* on some of the irrigation canals which receive their water from Kings River, convinced him that in porous soils the loss of water from the canal is dependent in no small degree upon the difference in elevation between the water surface in the canal and the elevation of the ground-water or water-table. As have all other observers, he found that the loss from the natural creek channel, which often has an unnecessarily broad bed but lies deep in the ground, frequently is less than from similar lengths of artificial canal. It was found also that the rate at which the water could be carried away from the vicinity of the canal, that is to say, the local effect of the canal-seepage upon elevations of the ground-water or water-table, materially affected the rate at which the water would sink into the canal-bed. The fact became notably apparent in such broad, flat regions as are found in some parts of the Sacramento and San Joaquin Valleys of California, that not all the water lost by seepage from the canals and ditches is an actual loss. Such seepage, together with much of the excess supplied to the field, found its way down to the ground-water and brought the same nearer to the surface of the ground.

Within a few years, the irrigation of a deep sandy loam near Fresno brought the ground-water up from an original depth of 30 to 60 feet to within 4 to 10 feet of the ground surface.† In the Munsel Slough country, California, near Hanford and Lemoore, where the slope of the ground surface is only 2 to 3 feet per mile, this effect of seepage losses from canals and ditches upon the elevation of the ground-water is so pronounced that it was made the method of irrigation. The loss from the main canal supplemented the infiltration from the laterals and the field ditches. The irrigation is complete when the ground-water is brought within easy reach of the surface soils by capillary attraction.* Of course, methods of irrigation which are dependent upon raising the ground-water to within easy reach of the surface soils, generally are undesirable and should be regarded only as temporary expedients, be-

* Water-Supply & Irrig. Papers, No. 18, U. S. Geol. Survey.

† Water-Supply Paper No. 18, U. S. Geol. Survey.

cause a preponderance of upward movement of the water in the soil will concentrate (due to the evaporation from the surface) its alkaline contents near the ground surface; and therefore such a method, if long continued, is an element of grave danger. Mr. Grunsky.

Nevertheless, in a region thus irrigated the term "gross duty of water" may take on a different meaning from that in other regions, where all irrigation water is applied to the surface.

Without any exhaustive discussion of the losses in transit from the source of water to the field, Mr. Grunsky presents in tabular form certain conclusions relating to losses from canals and ditches, amplifying the information presented by the author. The values in the table should be regarded as tentative and suggestive only, but yet may be found serviceable until supplemented by tables based on more complete data than were available when these tables were prepared.

Loss of Water from Canals and Ditches.

The losses include evaporation.

Approximate Table.

Applicable only when the ground water near the canals is at least 5 feet lower than the water surface of the canal. The loss is noted per square foot of water surface. To find the loss per square foot of wetted canal-bed, reduce the amounts noted in Columns 2, 5, and 8 by 20%, for a discharge of 1 sec.-ft., 10% for a discharge of 10 sec.-ft. and 5% for a discharge of 1000 sec.-ft.

Discharge Cu. Ft. per Sec.	Ordinary Loam			Sand and Sandy Loam			Gravel and Coarse Sand		
	Loss in 24 hrs.		Loss in per cent per Mile	Loss in 24 hrs.		Loss in per cent per Mile	Loss in 24 hrs.		Loss in per cent per Mile
	Cu. Ft. per Sq. Ft.	Cu. Ft. per Sec. per Mile		Cu. Ft. per Sq. Ft.	Cu. Ft. per Sec. per Mile		Cu. Ft. per Sq. Ft.	Cu. Ft. per Sec. per Mile	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	.90	.120	12.0	3.50	.50	50.	5.50	.75	75.
2	.90	.160	8.0	3.40	.60	30.	5.35	.95	50.
3	.89	.195	6.5	3.30	.70	23.	5.25	1.10	35.
4	.89	.210	5.3	3.20	.80	20.	5.10	1.25	30.
5	.89	.230	4.6	3.15	.90	18.	5.00	1.35	27.
6	.88	.240	4.0	3.10	.95	16.	4.90	1.45	24.
7	.88	.250	3.6	3.05	1.00	14.	4.80	1.55	22.
8	.88	.260	3.2	3.00	1.05	13.	4.70	1.60	20.
9	.87	.265	2.9	2.95	1.10	12.	4.60	1.65	18.
10	.87	.270	2.7	2.90	1.15	11.5	4.50	1.70	17.
20	.86	.37	1.9	2.85	1.40	7.0	4.45	2.10	10.
30	.86	.46	1.5	2.80	1.60	5.3	4.40	2.50	8.
40	.85	.55	1.4	2.75	1.80	4.5	4.35	2.90	7.
50	.85	.64	1.3	2.70	2.00	4.0	4.30	3.30	6.5
60	.84	.72	1.2	2.65	2.20	3.7	4.25	3.60	6.
70	.84	.80	1.15	2.60	2.35	3.5	4.20	3.90	5.5
80	.83	.87	1.10	2.55	2.55	3.2	4.15	4.20	5.
90	.83	.94	1.05	2.50	2.70	3.0	4.10	4.40	4.8
100	.82	1.00	1.00	2.45	2.90	2.9	4.05	4.60	4.6
200	.82	1.60	.80	2.40	4.00	2.0	3.85	6.10	3.0
300	.82	2.10	.70	2.35	5.10	1.7	3.70	7.60	2.5
400	.81	2.50	.60	2.30	6.20	1.6	3.60	9.00	2.3
500	.81	2.80	.55	2.25	7.30	1.5	3.50	10.50	2.1
600	.81	3.05	.51	2.20	8.00	1.3	3.40	12.00	2.0
700	.80	3.30	.47	2.15	8.70	1.2	3.30	13.00	1.9
800	.80	3.55	.44	2.10	9.40	1.2	3.20	14.00	1.8
900	.80	3.80	.42	2.05	10.10	1.1	3.10	15.00	1.7
1000	.80	4.00	.40	2.00	10.80	1.1	3.00	16.00	1.6

Mr. Grunsky. It is notable that the infiltration rate per unit of water surface area is larger for a small ditch than for a large canal. The difference is not great in dense soils, but it becomes marked in sandy loams, sands and gravels.

Another factor which influences the duty of water, and which perhaps has not been emphasized sufficiently by the author, is the method of irrigation. The size of the check and the length of the furrow should be adjusted to the irrigation head. In ordinary soils, for each inch in depth of water applied to the surface, the replenishment of moisture in the soil will extend downward about one foot. If at some time during the year the rains are copious, irrigation brings the water contents of the soil up to maximum retention throughout the upper 8 to 10 feet, the surface application thereafter of 3 to 6 inches of water once every 30 days during the irrigation season will supply all the needs of the growing plants. This does not mean that a single application of irrigation water once in 30 days always will be sufficient—for there are firm soils, sometimes somewhat colloidal in nature, which resist the penetration of moisture and therefore do not let the applied water sink in; and which, receiving benefit from only a small amount of water in the upper soil layers, therefore need a frequent replenishment of the water.

The fact that the methods of irrigation which have become established in various parts of the country are not always the methods best adapted to local conditions should be kept in mind when use is made of the tabulated results presented at the close of the author's paper.

Mr. Smith. **Mr. G. E. P. Smith,*** M. Am. Soc. C. E. (by letter), stated that Dr. Fortier's excellent paper on "Duty of Water" should be of great interest to all irrigationists, both engineers and ranchmen; and that the importance of the subject fully justified further discussion of the paper.

In analyzing the factors which influence the duty of water, under the head "Climate" the author has named rainfall as the climatic factor exerting the greatest influence. Mr. Smith believes, however, that in the arid and semi-arid portions of the country where irrigation is a necessity, the evaporation (and transpiration) rate is the factor of by far the greatest importance. In 1914, in discussing a paper on "The Determination of Safe Yield of Underground Reservoirs of the Closed-Basin Type"** he pointed out the close relation between evaporation rate and duty of water. Briefly the evaporation rate is a measure of the transpiration rate, and (other factors such as character of soil remaining constant) the transpiration rate determines the water requirement of the plants. The annual transpiration rate includes the influence of the length of the growing season.

As pointed out by the author, the measurement of transpiration losses is exceedingly difficult. Evaporation rates, however, are obtained

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** Trans. Am. Soc. C. E., Vol. LXXVIII, p. 230.

Mr. Smith.

easily. They should be obtainable today from the U. S. Weather Bureau records, but unfortunately there has been so great a diversity in the size and shape of evaporation pans and in their exposure, that to a considerable extent the evaporation records now available are not comparable. Standardization by the Weather Bureau is highly desirable, and doubtless when such standards are once adopted, all other agencies attempting evaporation measurements will conform to such standards.

Mr. Smith proposed the following general method for determining the maximum duty of water:

First, at two or three places in each State, measurements of the duty of water should be established and maintained for several years, similar to the measurements successfully conducted at Davis, California; the places selected for these measurements may be called base-points.

Second, evaporation measurements should be made at many places in each State, using in all cases standard evaporation tanks and standard exposures. Then, the maximum duty of the water (including rainfall) at the base points having been determined, the duty for the same crops and for similar soils in other locations can be computed by applying the ratios between the evaporation rates at the base points and the special points. Studies conducted at the base points will determine also the duty-of-water ratios between different crops and between different soil types.

Third, having thus derived the maximum duty for a particular locality, a judge, a water commissioner, or a designing engineer, should add a reasonable percentage for inevitable waste, in order to obtain an actual working net duty of the water.

The tendency has been to accept the results of duty-of-water measurements as applicable throughout a State and even in adjoining States. In the demand for greater water economy, there is danger that the pendulum may swing too far in that direction in the more arid States, with resulting injustice to vested interests. Even now, in southern Arizona there are irrigation engineers advocating a duty of 2 acre-feet of water per acre per year for alfalfa.

To illustrate the great variation in duty of water within a State, it may be mentioned that alfalfa at Lakeside, Ariz., requires only about one foot depth of irrigation per year; while in the Sulphur Springs Valley two and a half acre-feet are required; in the Salt River Valley from four to five feet, and at Yuma not less than six feet. Inside of these limits the law of diminishing returns does not apply. In California the variation is perhaps equally great. To adopt averages for an entire State produces duties of water which are inapplicable anywhere and which are likely to mislead Courts and others who are charged with the determination of water-rights and the equitable division of water. Duty of water is a very local question, and averaging should be done with the greatest care or avoided wholly.

Carefully conducted investigations are greatly needed and should be multiplied. The ordinary duty-of-water tests, however, in which are measured only the quantity of water applied and the acreages, are of

Mr. Smith. little service; indeed, often such tests are quite worthless because of unfavorable factors that are overlooked entirely. To illustrate this point, Mr. Smith once measured the duty of water on what was intended to be a model alfalfa field. It was found that 108.2 in. depth of water was applied to produce seven cuttings, totalling eight tons per acre. An investigation of the downward percolation of the water proved that about one half of the water was sinking to the ground-water table without accomplishing any useful function. The loss occurred on the upper portions of the land near the head ditch, yet the stand of alfalfa was uniformly good over the land. The conclusion, of course, was that the lands should have been shorter or should have been given more slope. But what farmer investigates the downward percolation of the water? In Arizona there are many fields where the lands are laid out one-half mile long and the loss downward must be considerable. In other cases the slope is too great, the irrigations are too frequent, or the crops actually may suffer for lack of water. In all such cases the ordinary blind duty-of-water tests are misleading. What we need to know is, not how much water farmers are using, but how much they are justified in using.

He was interested in Mr. Griffin's statement that all the farmers may desire the water for alfalfa irrigation at the same time, just after the first cutting. There is much to be said in favor of irrigating from one to two weeks before cutting, just long enough to permit of the soil drying out sufficiently for the teams. The water requirement of alfalfa is practically nothing immediately after cutting, but increases thereafter as a hyperbolic function of the time, so that during the last third of the period of plant growth, the demand for soil water is very great. When the irrigation is applied just after cutting, there must be considerable loss by evaporation from the soil. With the practise suggested (irrigating from one to two weeks before cutting), this soil evaporation is reduced, and yet the soil moisture will be such as to give the new growth a good start. Of course the suggested practice applies to conditions where one irrigation suffices for each cutting, the ideal practice for all except very porous soils.

Mr. Peters. **Mr. F. H. Peters,*** Assoc. M. Am. Soc. C. E. (by letter), stated that the author's paper covers the whole matter as a general subject very adequately, and it is difficult to add anything of value by a general discussion of the subject. However, it seems appropriate in discussing this paper, read before an International Engineering Congress, that stronger attention should be drawn to the necessity for a better understanding and a clearer and closer definition of the meaning of the term "Duty of Water". The author has indicated that (particularly by the use of prefixes) the term "duty of water" has been used with so many different qualifications and meanings that its meaning has become ambiguous to an extent most undesirable for technical or practical usage.

It may be accepted as axiomatic that the duty of water means

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the relation between a certain commodity (water) and the area of land that it will serve; and while for certain purposes of design and operation it may be more convenient to consider a rate of flow in relation to an area of land, still it is thought that the best practice accepts the most desirable definition as that stating a certain quantity or volume of water required for a certain area of land. If this much be conceded, then the same features that are admitted as essential in dealing with any other commodity should require that the definite place and period of delivery be fixed. This seems clear and business-like. We have land that requires a certain commodity (water); and therefore any estimate of requirement or any contract for supply should state definitely the quantity of water, the place of delivery, and the period of delivery. Mr. Peters.

For practical purposes there always will be two meanings attached to the term ''duty of water'', indicating the quantity of water involved and measured at the farmer's field and also the quantity of water involved and measured generally at the source of supply. As the only useful quantity of water is that which is delivered at the farmer's field, where it actually is available for application to the soil in which the plants are growing, it is held that the true meaning of the term ''duty of water'' should refer to the measured quantity at the field. However, the engineer or irrigator is equally interested in the quantity of water which must be measured at the source of supply or at some other particular point in order to produce the true duty at the field, and which quantity includes the true duty plus such further duty as may be required to provide for the unavoidable losses in the transportation of the water from its source or from some other point to the field.

It is felt that primarily and for practical use, two rigid definitions of duty of water should be adopted and always used as indicated below, while for scientific or professional discussions other prefixes could be used giving special meanings:

> Net duty of water should mean the quantity of water per acre per irrigation season actually applied and used at the field.
>
> Gross duty of water should mean the quantity of water per acre per irrigation season which must be applied at any stated place in order to produce the net duty of water at the field.

It is noted further that the best practice on the American Continent appears to accept as the most desirable units for use in this connection, the acre and the acre-foot.

A discussion of the definition of the duty of water cannot be complete without a consideration also of what is commonly termed the ''delivery head'', or the ''irrigation-head'', which means the actual rate at which the water is supplied to the farmer during actual periods of use.

The author has made very clear the various factors which affect not only the quantity of water required during any annual period, but also the great variation in the requirement of water during short periods in any year. In short, while practical requirements for any determination

Mr. Peters. of or contract for the supply of water make it desirable to fix a duty of water as governing a stated quantity of water delivered at a stated place in any stated period, yet the further practical requirements in the field make it necessary that the rate of delivery during actual use be stated also, in order to meet the requirements of the crops and of practical usage.

The matter can be presented most briefly by the acceptance of the fact that the duty fixes a quantity of water to be delivered during an annual period, and that the quantity is measured by a multiplication of the rate of supply and the time factors. While it is admitted to be the practice in certain districts, still it seems inconceivable that a constant rate of supply during the whole annual period can be either efficient or truly beneficial.

In the first place, for a very small farm unit the constant rate of flow would not create a usable head; and it must be accepted as a fact that for general conditions the larger the head (up to a reasonable limit) the more efficient the use; and secondly, it is hardly conceivable (except perhaps in the most southerly districts) that any farm unit could have such a diversified selection of crops that the constant rate of flow could be utilized in aiding plant growth continuously throughout the annual period.

There seems to have been a tendency in American law and practice to confuse the terms "duty of water" and "irrigating head". It should be pointed out to the farmer that his best interests can be served only by a contract which ensures to him a reasonable duty of water and also a reasonable irrigating head, while it may not be amiss to point out to the engineer that the only safe design for any supply canal is one where the computations for capacity are based not only on the gross duty of water but also on the requirement of maximum irrigating capacity, which reckons with the requirements of the farmer's irrigating head. A definition of irrigating head which might be adopted is as follows:

> The "irrigating head" means the rate at which the net duty of water is supplied in order to promote the most efficient and beneficial use of water in the field.

Dr. Fortier has quoted so many useful figures concerning duty of water in the United States that it may be of interest to add a few notes in this respect regarding the provinces of Alberta and Saskatchewan in Canada. In these provinces, a Dominion law fixes the irrigation season as the 153 days from May 1 to September 30, and also fixes the legal net duty of water as 2 acre-feet per acre per season; while recommendations have been made for a regulation requiring the net duty to be delivered with a sufficient irrigating head, fixed at about 2½ cu. ft. per sec. for each 75 acres of irrigable land.

Duty of water investigations have not been carried on as yet for a sufficient length of time to permit of reliable figures being quoted, but records for three years indicate forcibly that the legal duty mentioned above is more than ample.

Mr. H. B. Muckleston,* M. Am. Soc. C. E. (by letter), stated that, as the author points out, the term "duty of water" covers a wide variety of uses. It is regrettable that this is the fact, but custom and usage must be conformed to. Mr. Muckleston.

In Canada or in that part of it where the Federal Law governs, the term is defined in the Irrigation Act as "the area of land which can be irrigated by a unit quantity of water—which is defined further as a discharge of one cu. ft. per sec. flowing constantly during the irrigation season".

The Act does not state where this unit quantity of water is to be measured, and thus there is an opening for confusion and argument as between the net duty and the gross duty, as defined by the author. The place of measurement usually determines the way in which the duty is expressed. When measured at the field or at a storage reservoir, a volumetric relation gives the best result; whereas when measured in the flowing stream, it is probable that the time-rate relation is preferable.

Much of the confusion in the use of the term "duty of water", in America at any rate, is due to the attempt to create by law a uniform duty over state-wide areas, where governing conditions of all sorts vary between wide extremes. As an example: the two provinces of Alberta and Saskatchewan, making together an area covering 8° of longitude and 11° of latitude, where the altitude varies from 5000 to 1400 feet above sea, and the rainfall from 30 to 11 inches per year, both come under the Northwest Irrigation Act and the legal duty is the same throughout the whole area. The absurdity of this is evident; for as a matter of fact, on some of the larger projects the actual water requirement varies to a considerable degree even within the project.

The use of the term "duty of water" should be confined to some one phase of the general question, and other terms should be found or invented for other phases.

Prof. S. T. Harding,† Assoc. M. Am. Soc. C. E. (by letter), stated, in discussing Dr. Fortier's paper, that the public may be interested in getting the greatest return per unit of its resources or the maximum yield per acre-foot of the water available; but the individual is interested in securing the yield from the definite area which he owns which will bring him the greatest profit. The public interest may be to secure the maximum irrigated acreage, but the individual interest is to secure the maximum return per acre. Prof. Harding.

In comparing the amount of water used with the resulting yield, it is usual to find that the yield increases with an increase in the depth of water applied until a point is reached where the use of more water tends to reduce the yield. Before the point of decreasing yield is reached, however, there is a considerable variation in the amount of water used within which no marked variation in the yield may occur.

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† Assistant Professor of Irrigation, University of California, Berkeley, Calif.

Prof. Harding. This range in the depth used occurs within the usual variations of ordinary practice. It is this condition which makes it difficult to demonstrate the most economical practice when based on comparison of yield alone. It is necessary to follow the water on to and into the soil, and determine the economy of its use from its disposal on the land.

Investigations should be planned so as to determine the proportion of the total depth of water applied which is used by the crop. The losses are of three kinds—surface waste, soil evaporation, and deep percolation. The surface waste is observable readily and its amount may be measured; and means for its prevention also can be used. Soil evaporation is known to occur, and some relative measurements of its amount are available under certain conditions. There are some results available which show the effect of various practices in reducing evaporation, but some of the results for different types of agriculture do not agree in this respect. Deep percolation losses are not visible to the irrigator, and probably their extent is not realized. Most of the investigations of the use of water recently undertaken, or now being made, include the tracing of the moisture in the soil, at least to some extent. And again soil can retain only a certain amount of moisture within reach of the crop roots, and water applied in excess of this amount passes beyond the reach of the plants or water-logs the soil. The soil moisture capacity, above the point to which it is desirable to allow the soil to become dry, under certain conditions gives a measure of the maximum amount of water which it is desirable to apply at a single irrigation. Much information on this point is becoming available, and much more is being secured.

Tank experiments of various kinds are useful to secure certain relative results. The actual use and application of water must be under field conditions, and all results finally must be tested in the field. All crops grown in tank experiments are under more or less artificial conditions, so that the results obtained can be only indicative rather than conclusive. For this reason, experiments under actual field conditions are much more preferable, and results thus obtained will be much more convincing both to irrigators and to courts. An illustration of this is shown in the author's paper, where the records secured at Davis, California, in 1912 gave an average transpiration ratio of 706 pounds of water per pound of alfalfa. Field experiments on the same soil in 1910 to 1914, where the depths of irrigation water used vary from 0 to 48 inches, in addition to an average rainfall of 16.4 inches, gave yields varying from one pound of crop for every 430 pounds of water received by the land where no irrigation was used, to one pound of crop for 770 pounds of total water received where 48 inches depth of irrigation was used. A depth of irrigation of 30 inches per season, which the results indicated to be the preferable practice, gave a yield of one pound of crop for 580 pounds of total water. As these amounts include evaporation and any deep percolation that may have taken place, the actual transpiration ratios would be much less.

Prof. Harding.

The question of the best duty of water under given conditions necessarily is complex. Results which can be applied outside of the actual conditions under which they are secured can be obtained only when all factors, including yield, soil, soil-moisture, time of application, and depth used, are determined and their relative effects studied. In the past, there has been much need for records of actual use, without many data on the reasons for such use, in order that canal capacities could be determined and general adjudications made. In the future, the need is more for intensive study in the fields, to assist the individual irrigator in determining the best practice for the varying conditions found even on adjacent farms.

Mr. True.

Mr. James B. True* (by letter) stated that the subject of the duty of water in irrigation covers an almost inexhaustible field, and discussing it in so small a space as the author's paper necessitates a very general treatment, touching only briefly on a few of the most salient features.

In our arid and semi-arid western States, irrigation is of vital importance. The time approaches swiftly when every drop of water available will be utilized to its utmost capacity, to reclaim as large a proportion as practicable of our millions of acres of arid lands. Water is our greatest natural resource and, although limited in amount, it is permanent and perpetual. Our available water-supply will be exhausted long before we have reclaimed all of the arid lands susceptible of irrigation. The value of water for irrigation therefore is sure to double and treble, and we must see to it that we secure a maximum beneficial use of the water-supply available.

This will involve a careful and accurate study of each and every stream, the determination of the precipitation, run-off, character of the soil, climate, etc., and the building of storage reservoirs along the streams at such feasible sites as nature has provided, to control the floods and store the winter run-off. With these various factors determined and proper storage provided, the amount of water actually applied to the lands tributary to the particular stream may not be the most economic duty of the water. If the available water-supply of a stream exceeds the demands of all the land that can be irrigated from that stream, the duty of water will tend to be low, and if there is more land susceptible to irrigation under a stream than can be reclaimed properly by the water available, the duty will be correspondingly high. However, in order to secure the maximum beneficial use where the former condition exists, the surplus water should be allowed either to flow down its natural channel to join another stream and afterward serve lands lying below their confluence, or, where feasible, should be diverted into another drainage area to serve lands where the natural water-supply is too small.

Near the head of the stream, where the elevation is comparatively high, the climate cold and the growing season short, the amount of

* State Engineer, Cheyenne, Wyo.

Mr. True. water applied at each irrigation is larger. In some parts of the Upper Green River in Wyoming, there is a killing frost nearly every month of the year, yet native hay and the hardier grains are grown successfully in this district. The water users cover the land about half a foot deep with water during the frosts to prevent injury to the roots of the growing plants. Much of this surplus water returns rapidly on the surface of the stream, and a considerable amount returns slowly by seepage and deep percolation.

Natural storage thus created by seepage and deep percolation provides additional water for irrigation uses lower down the stream where the growing season is longer. Late appropriators on a stream, being subject to all prior appropriations, are forced to depend for their diversions on periods of flood. Being restricted in their use of water to short uncertain periods, naturally while the floods last they use excessive amounts of water. Flood water thus diverted and spread over the land returns slowly to the stream as seepage and tends to increase the normal low-flow of the stream below.

Pioneer irrigators having secured their rights in the early days when there was an abundance of water, naturally tend to use much more water than can be applied to the land beneficially. This condition is being adjusted automatically to a large extent, and the late appropriators are demanding that the early ones be restricted to the legal amount of water called for by their rights.

An economic duty of water depends not only on the amount used, but also on the time and method of application. It is the prevailing custom to use too much water during the growing season of the crops. The roots of a growing plant spread only sufficiently to secure the amount of moisture necessary, and too much water thus retards the growth of the roots. Smaller amounts of water applied scientifically at the critical periods will cause the roots to spread and seek additional moisture, and therefore will produce a hardier and better matured plant. Care should be taken also during the later irrigation. During the hot dry season when the crops are ripening, water should be applied in the evening, as it will then soak further into the ground and leave the surface dryer, and be less apt to form a crust to choke the plant during the heat of the day.

Beneficial use is coming to be the universally recognized basis for all adjudications of water. In the case of Farmers' Co-operative Company vs. Riverside Irrigation District, 16 Idaho, page 525, the Court said:

> "In determining the duty of water, reference should always be had to lands that have been prepared and reduced to a reasonably good condition for irrigation. Water users should not be allowed an excessive quantity of water to compensate and counterbalance the neglect and indolence in the preparation of their lands for their successful and economical application of the water".

Decisions such as the above, based on sound principle and good practice, are doing much to aid in establishing the principle of an economic duty of water. Mr. True.

Also, much good can be accomplished through proper legislation. All continuous-flow methods should be eliminated from our western States, substituting the acre-foot as the unit of measure; and the amount of water permitted to be used in each case should be limited to that which can be applied beneficially with economical methods. The legal rate of use should be increased so as to enable the irrigator to use large heads of water over short periods, as this has been proved the most economical method of irrigating.

The most permanent results and the greatest advancement toward securing the maximum beneficial use for irrigation of our available water-supply are being accomplished through the irrigation investigations being conducted by the U. S. Department of Agriculture under the direction of Dr. Fortier. The value of this work can not be over-estimated. It is teaching the irrigator the science of irrigation, and convincing him that beneficial use of water works for his own best interests as well as for the best interests of the entire nation.

Mr. O. L. Waller,* M. Am. Soc. C. E. (by letter), stated that possibly 40% of the water rights of the United States have been adjudicated and the duty fixed by Court decrees. As new rights are initiated and old ones developed, the Courts will more and more be asked to fix the duty of water. But in doing this their decrees must follow the testimony before them. They can not establish a general duty of water for a State, but only one for the specific lands involved in the litigation before them. Sometimes they award fabulous quantities of water for an area of land, but when low duties are decreed, it is always because the testimony offered has shown a necessity for only the quantity of water fixed by the Court. Mr. Waller.

In a case reviewed by the Supreme Court of Oregon, Whited vs. Cavin, 55 Oregon, 98, upon the testimony of witnesses the lower Court had awarded a flow of water sufficient to cover an acre of land 25½ feet deep each month—or 102 feet deep in an irrigation season of 4 months, or a little over 10 acre-inches of water per acre for each day.

Many of the decrees fixing the duty of water are based upon the testimony of witnesses who are wholly unqualified to give testimony in such matters. In most instances they do not know how much water a crop requires, and frequently they are themselves wasteful users of water.

It is important that an economical use of water be fixed by our Courts; but to bring this about it will be necessary, in all cases involving rights to the use of water, to introduce expert testimony showing the water requirements of the land for which the duty is to be fixed. This could be brought about by making the State (representing the public)

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Mr. Waller. a party to all such litigation, and making it the duty of the Attorney General or his representative to protect the rights of the public, and to introduce testimony that would assist in establishing an economical duty.

The present method of employing experts frequently minimizes the credibility of their testimony. This could be remedied by empowering the Court itself to call such experts, and thus do away with any tendency toward partisanship in such testimony. Many field investigations have been made and much scientific work has been done in studying advisable duties of water; only the Courts have the power to fix high duties, and unless the results of such studies can be brought before the Courts and the juries, as absurd decrees as were given in the Oregon case above noted will continue to be entered.

Under the present practice, the rights of the public in the use of the waters of the State generally are not presented to the Courts. Frequently the litigants are anxious to divide up a public commodity so that each shall get as large an amount as possible. This desire brings about wasteful methods of distribution and use.

All matters tending to fix the amount of water economically required by the lands involved in any litigation may be introduced in evidence and the machinery should be provided for the introduction of such testimony in every case involving the right to the use of water for irrigation purposes.

''Water users should not be awarded an excessive quantity of water to compensate for and counterbalance their neglect or indolence in the preparation of their lands for the successful and economical application of the water''* nor for their lack of knowledge of good irrigation practice.

The courts will insist that water be economically conducted and applied to the land without necessary loss.

Kinney further says: ''The water supply of the country should be conserved to the greatest possible extent consistent with its successful use for all beneficial purposes for which it may be appropriated''.

No vested rights to continue wasteful methods are acquired by a prior appropriation.

> ''The wasteful method so common with the early settlers can be deemed only a privilege, permitted merely because it could be exercised without substantial injury to any one; and no right to such method was acquired thereby'', Hough vs. Porter, 51 Oregon, 318.

Efforts to save water have been advocated long and strenuously, but the water user claims that water so saved will be for the benefit of the ditch owner, permitting him to sell more water-rights and increase his speculative profits. A campaign should now be organized to show the water-user that he may benefit himself by an economical use of the water.

In fixing the ''duty of water'', the first element to be considered is the plant requirement. All quantities of water in excess of that needed

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* Kinney on Irrigation and Water Rights Sec. 904.

by the plant to produce a vigorous growth are in some way a detriment to the land to which they are applied. Such excess water, running off from the land or running through into the drainage, carries away valuable plant food; or it may raise the water-table or ground-water until the lands are water-logged or until the rise of alkali prevents the raising of crops. Mr. Waller.

Most of the questions connected with the duty of water could be solved easily and readily if water were paid for by the acre-foot. All new contracts should provide that water be paid for on a quantity basis. It is quite likely that when the water-users own and operate their own irrigation systems, they will find such a method of delivery most beneficial to themselves and most economical.

Mr. F. L. Bixby,* Assoc. M. Am. Soc. C. E. (by letter), stated that the author's paper on the duty of water in irrigation is the most complete presentation of the subject he has yet seen; the author has set forth in clear statements the results of his years of observations, based on actual investigation work. As he states, "no other subject connected with irrigation covers so broad a field as the duty of water"; and the subject is such a broad one and is influenced by so large a number of factors that its determination cannot be arrived at conclusively from one season's set of observations. Mr. Bixby.

In Mr. Bixby's opinion, the duty of water in irrigation (when viewed from the standpoints of the legal, administrative, engineering, economic, and agricultural phases respectively) covers the whole subject of irrigation; as in the collection of the necessary preliminary data for each of these important factors, the subject of irrigation will have been investigated thoroughly from its inception in the acquiring of water-rights in the beginning, through the storage, diversion and conveying of the water, to the culmination of the irrigation by the use of the water in its application to crops.

While the agricultural phase is fifth in the author's stated cycle of development, primarily it is first and foremost in the ultimate aim to reclaim the desert. It deals with the purpose for which litigation has been employed, viz., the production of crop yields maximum in quantity and in quality and with a minimum water requirement. When irrigation is once established, all other phases fall to the background; but agriculture is one constant experiment with new crops, new methods of cultivation, and of seeding and harvesting.

The agricultural phase of the duty of water in irrigation includes a study of the relation of water to the soil and to crop production; the conserving of moisture by cultural methods; the effect of fertilizers and the availability of plant foods in their relation to irrigation waters; the distribution of irrigation water in the soil; studies in the methods of applying water and of their adaptability to specific crops; the best time to irrigate relative to seeding and to harvesting; the mean moisture

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Mr. Bixby. required consistent with good plant growth; the selection and improvement of seeds with special reference to irrigated agriculture; and the best relative amounts of water per unit weights of resulting crops.

The time seems to have passed when the most important work was to prepare for the storage of water and the building of ditches, without first investigating markets, favorable crops and practicabilities of colonization. It has been found too often that the source of supply was inadequate to meet very large agricultural demands, and, in consequence, prospective settlers have been ruined financially by being encouraged to purchase farms before the water-supply was available.

Water has been used in a profligate manner and much land has been ruined by over-irrigation. Today the trend of irrigation practice is toward more permanent and more efficient irrigation structures and a more economical use of the water. It is being realized also that the proper levelling of the land (consistent with topographical conditions) is an important adjunct to the uniformity of the distribution of the water and the production of the crops. The growing population of irrigated areas and the scarcity of water have emphasized the importance of a more frugal use of water. The losses of water from canals due to seepage have encouraged the lining of canals, to conserve the water as much as practicable in conveying it to the irrigated fields. In every irrigated section the use of water in all its phases is being studied with a view to increasing its efficiency for larger service. All this activity has been stimulated by a better knowledge of the duty of water in irrigation.

The ultimate result of all this activity has been and will continue to be the extension of the irrigated area to the limit of service of the water-supply; the prevention of the water-logging of the soil and consequent alkali condition; the better preparation of land before irrigation is attempted; the growing of larger and better crops; and the establishment of larger, more prosperous and more contented communities wherever irrigation is practiced.

Mr. Hammatt. **Mr. W. C. Hammatt,*** M. Am. Soc. C. E. (by letter), stated that one reason the amount of water required for irrigation of a certain crop is so difficult of determination by comparison with the use on similar lands for which data are available, is that the use in such localities is generally based on the quantity of water available rather than on the actual quantity necessary. There is no doubt that where water is plentiful an excessive use has been made by irrigators, due to their desire to get all they are entitled to, regardless of the effect it may have on their own and near-by land. It is also a fact that much water has been wasted by inefficient methods of application. The data gleaned from systems under these conditions have given rise to much of the doubt as to the adequacy of the 2½ acre-ft. per acre estimated as the ultimate irrigation need of the irrigable land under the flow of the Tuolumne River. How-

* Cons. Engr., San Francisco, Calif.

ever, there is a constant tendency of irrigation systems to use less water and a consequent constant decrease in the waste of water. Mr. Hammatt.

As Chief Engineer of Miller & Lux, Inc., he had occasion to make very accurate determinations as to canal losses and as to the duty of water applied to the land under the San Joaquin and Kings River Canal and Irrigation Company's system, extending over several years. The results of the investigations were as follows:

(1) That 45% of the water taken into the system was lost by percolation and evaporation in the entire system.

(2) That the quantity of water measured as flowing to the land for irrigation was 2.44 acre-ft. per acre for 1907, 1.49 acre-ft. for 1908, and 1.44 acre-ft. for 1909.

The drop in the quantity used in 1908 below that used in 1907 was due to the company's change in irrigation charge from an acreage basis to a quantity basis. Prior to 1908, the rate was made per acre irrigated, regardless of the quantity of water used thereon, but, in that year, the rate was changed to so much per second-foot for 24 hours. This change was made for two reasons: First, because the extraordinary demand for water was forcing the system beyond its capacity; and second, because the excessive use was drowning the land. The result of the change was fully up to expectations, as the irrigators, when they were obliged to pay for the water used, reduced their use to their needs. Although the company has since returned to the acreage basis of charges, the educational work has been lasting, and the demand still remains as it was during the years when the rates were fixed on the quantity basis. The duty previously given was for all crops, the prevailing crop, however, being alfalfa, about 70% of the land being irrigated for this crop.

Mr. Hammatt is very familiar with the land on the east side of the San Joaquin Valley from the Stanislaus River to the Kings River, and has made several examinations of irrigation systems in this area. From his knowledge of the conditions in this territory, he is able to deduce the following conclusions:

(1) That the canal losses in the Turlock and Modesto Irrigation Districts would be considerably less than those under the San Joaquin and Kings River Canal and Irrigation Company's canal system, due to the lesser canal length and greater fall of the former. The losses from seepage and evaporation in the Modesto and Turlock Irrigation Districts would undoubtedly fall below 35% of the total intake.

(2) That the necessary use of water on the land in these districts would be at least as small as that under the San Joaquin and Kings River Canal and Irrigation Company's system, as the soil evaporation would be less and the sub-surface drainage probably no greater. This conclusion is deduced from an intimate knowledge of the soil conditions in both localities.

The necessary use of water, then, as measured at the intake, would be, considering 1.5 acre-ft. per acre necessary on the land itself,

Mr. Hammatt. $1.5 \div 0.65 = 2.31$ acre-ft. Or, if the gross acreage is considered, as about 20% of the land is occupied by roads, buildings, yards, and other non-irrigated tracts, the necessary quantity for the whole area would be 80% of 2.31, or 1.85 acre-ft. per acre. It would seem therefore that an allowance of 2.5 acre-ft. per acre per year would be an ample water-supply as an average for the irrigated lands of the Turlock and Modesto Irrigation Districts, and in general for all the irrigable lands under the Tuolumne River; and that this supply would meet all contingencies of waste due to canal regulation, individual excessive use, and whatever other extraordinary conditions might arise. Although there is little question that a greater quantity of water than this has been used in the past on these lands, it is apparent that the quantity used has been in excess of the needs, as is shown by the rise of ground-water and the drowning of the crops in many localities.

Mr. Adams. **Mr. Frank Adams*** (by letter) stated that the author's paper presents data of much value; and while, as the author says, much additional data might have been presented, still enough ground is covered by the paper to indicate the nature of the problem as it confronts the irrigation engineer and the agricultural specialist in irrigation in western America.

Dr. Fortier indicates in the paper the changes that have come about in recent years in the methods of studying the duty of water in irrigation, to-wit: a change from a study of the amounts of water used to a study of the amounts required. It would seem that engineers well can interest themselves in these new methods. Insofar as they result in the prevention of waste, engineers as well as the public are benefited, because every acre-foot of water saved required additional works to convey it. Therefore, looking at the matter merely from the selfish standpoint of the engineer, it would seem that he can well afford to support public agencies in accomplishing better control of irrigation waters.

The ideal in irrigation (at least from the public standpoint) obviously is what Dr. Fortier terms the "optimum duty", the duty that represents the largest possible profits in soil products from the use of a given volume of water, regardless of the area of land on which it is applied. It cannot be hoped that this ideal will be reached very soon, except in relatively isolated cases, nor would it seem to be economical as yet to attempt to do so on a wide scale. However, the principle involved must be kept clearly in view all of the time, to-wit: that each added unit of water applied to any crop gives a diminished crop return per such unit. For instance, a five-year experiment on the production of alfalfa at Davis, California, showed no substantial increase in yield after applying 2.5 acre-feet of water per acre per annum, and a definite falling off in profits. This is only one of numerous experiments which illustrate well the principle, and a general recognition of it should increase considerably the average duty of irrigation water.

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Mr. Adams.

Much of the present research into the duty of water to which the author refers has dealt with the water requirements of the plants irrigated. Other studies, largely under Dr. Fortier's direction, are dealing with the water-holding capacities of different soils as they are found in place—that is, these studies are seeking to trace the movement of the irrigation water in the scil and to determine how much of the water applied remains available to the plants. While engineers when called on to design irrigation works cannot afford to overlook entirely the amounts of water being used generally, it seems important that they recognize the fact that no duty can be counted as a permanent one that contemplates applying a greater quantity of water to the soil than that soil can retain against gravity, overlooking for the moment that which it can obtain from below through capillary action, and also overlooking how much less water the crops irrigated can utilize than soils will retain against gravity.

For instance, if it is found (as has been found in connection with some California soils) that an application of a depth of one inch of water at each irrigation for each foot in depth of soil is all those soils will retain against gravity, obviously it is poor economy to apply greater quantities than that, the excess to be wasted below through deep percolation. The point it is desired to emphasize is, not that water is wasted through deep percolation, because that is very well recognized, but that prior to adopting a duty, engineers should either themselves or with the aid of specialists obtain some definite idea through borings, moisture determinations, and soil analyses, of the amounts of water that soils will store up without excessive loss.

The paper refers to water-right contracts as one of the agencies influencing the duty of water. The author does not take any space to condemn the unfairness of these contracts as they usually are written, probably because he is referring to such contracts only incidentally. In California, under the control exercised by the Railroad Commission over all public service enterprises, matters of rates and service of irrigation enterprises engaged in public service are coming to be determined by the State rather than by the terms of such contracts; so that, in California at least, the public regulative authority must be considered as affecting the duty of water for irrigation.

The paper refers also to the effect on the duty of water of the plan of water delivery. This is illustrated well by a certain California irrigation enterprise that provided originally a 30-day rotation of the water and seemed quite intent on maintaining it. In the case of a substantial portion of the land served, it is impossible to keep the soil moist by monthly waterings or to accomplish by them greater penetration of the water than 10 to 12 inches, so that with a 30-day rotation interval the apparent duty is much higher than a duty that yields maximum returns in produce. In this case, a duty that approaches normal is reached only by means of a rotation plan providing for delivery at least three times per month.

Paper No. 39

DRAINAGE AS A CORRELATIVE OF IRRIGATION.

By

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Washington, D. C., U. S. A.

INTRODUCTORY.

Irrigated lands in the arid states occupy a prominent place in American agriculture. The United States census of 1910 reports that in 1909, 13,738,485 acres were under irrigation, representing an expenditure of $307,000,000 for the works which were required to bring water from the streams to the land. At this date (1914), it is estimated that 15,000,000 acres of arid land are under irrigation. The magnitude of this phase of agriculture fully warrants a careful examination and treatment of the problem of the over-saturation of irrigated land, which has assumed alarming proportions as a whole, and in many localities has become a serious menace to the well-being and prosperity of individual farmers, and frequently of entire communities.

Water, which is the all-commanding power in subduing arid wastes and bringing them into a state of fruitfulness, produces ruin upon the same lands when not properly controlled. So salutary and beneficent is the effect of water upon dry land that the necessity for its regulation and control after it has been collected and distributed upon the land by works or irrigation is not realized until the swamping of hard-earned fields warns the owner that the value of his lands is disappearing before the insidious march of seep-water and alkali. This swamping of lands under irrigation is more widespread than the public reports of the irrigation development in our country indicate, and furthermore, is increasing from year to year.

A conservative estimate of irrigated lands in the West which have become too wet for profitable cultivation is easily over a

million acres. In some sections fully twenty per cent of the land for which irrigation has been provided is non-productive because it is too wet. Water for these lands has been obtained at a large expense. A distributing system was provided and the land was successfully cropped until it became wet or until alkali began to burn the crops. Ordinarily the land owner was unaware of the approach of the evil until the crop on some part of his farm suddenly failed. Such a collapse is all the more aggravating and discouraging when, as often happens, adjoining land, for a time at least, remains uninjured. The land of one owner may be ruined while that of another in the same district, and apparently no more favorably located when developments began, may continue productive. One part of an irrigation district is often seriously injured by over-saturation while the other part enjoys immunity from the evil.

Conditions of this character, which prevail in all irrigated agriculture, demand the thoughtful attention of land owners and engineers, together with the cooperative effort of all concerned. It is the purpose of this paper to correlate the practice of irrigation and drainage, and, particularly, to show the methods of draining wet lands under irrigation as now successfully practiced in this country.

As a prelude to the treatment of the subject, the writer desires it understood that he has been closely identified with the development of the methods of draining irrigated lands since the need of such improvements first became manifest in the far West. In 1902, he was called by the U. S. Department of Agriculture to investigate the subject of drainage in connection with irrigation, the seepage and over-saturation of lands having assumed serious aspects in many localities. Careful observations and studies made in connection with cooperative experimental drainage in various parts of the West, while the writer was Chief of Drainage Investigations of the Federal Department of Agriculture, resulted in the evolution and development of the methods which are now successfully employed in every western state where irrigation is practiced. What he has to say, therefore, is derived from a personal familiarity with field conditions and with the various experimental steps that have attended this important series of practical investigations, which mean so much

to irrigated agriculture. It is not proposed to deal with the details of particular projects but to describe and illustrate the principles and general methods which are now recognized and followed in this country. Many incidents illustrating the human or personal element as a factor in drainage developments of this character would be of interest, but will be passed to give place to the more weighty phases of the subject.

PROCESS BY WHICH LAND IS SWAMPED.

The water for an irrigation system is brought from a river or reservoir by a canal along the upper side of the tract to be irrigated, and is distributed to the arable land by laterals leading out from the main canal, and thence over the fields by whatever method proves most successful for wetting the ground for growing crops. When once distributed upon the land, water not absorbed by the plants and soil particles passes downward into the depths of a soil which has been arid for centuries. No more perfect soil drainage can be imagined, as long as the subsoil reservoir has ample capacity, but when it becomes filled to the surface, every condition required for the formation of a permanent swamp is fulfilled.

When irrigation began in the Modesto District, California, in 1904, water was eighteen feet below the surface. Two years later the water had risen ten feet. In 1907, three years after irrigation began, water stood on the surface of ponds and low lands, making them untillable. It had risen fifteen to twenty feet within three years. This condition is not so surprising when we learn that in some parts of the district, sixteen feet of water was put on the land the first season of irrigation.

The Minidoka Irrigation Project in Idaho furnishes another example of more recent swamping of irrigated land. This district contains 64,000 acres lying from twelve to sixteen feet above the surface of the Snake River. The land is sandy and the subsoil a fine sand and gravel which it was predicted would furnish excellent natural drainage. Notwithstanding these conditions, it was reported in 1913, seven years after the district was opened up, that 16,000 acres, or one-fourth of the entire district, was in danger of swamping and that 5500 acres of that area could not be cultivated and were useless. It is estimated

by the engineer of the district that the loss of water by percolation into the soil after deducting the amount necessary for the support of crops during the seven years that the system has been operated would cover the entire project to a depth of twenty-four feet, or raise the water table seventy-five feet, provided there was a subsoil deep enough to contain that amount of water.

The Yakima Indian Reservation, in the state of Washington, contains lands which, after having been provided with water for irrigation, were noted for their productiveness. The lands have a gravel subsoil and a surface slope of about 10 feet to the mile toward a good drainage stream. Notwithstanding these favorable conditions, an examination made 12 years after the lands were first irrigated disclosed the fact that 40,000 acres had become water-logged and alkaline and, in consequence, were non-productive. Before irrigation began, it was necessary to sink wells from 20 to 40 feet to obtain water, but the same land after 12 years of irrigation, became boggy and miry. It may be said, in passing, that in 1911 and 1912, a few well located ditches were constructed by the Indian Bureau, the effect of which was to restore the land to its original productivity. The general plan of drainage is shown in Fig. 6.

Whether the excess of water comes from percolation through the bottom and sides of the canals, from over-irrigation or any preventable cause, the fact remains that some lands in all districts, under ordinary management, are being swamped and their owners ruined. Better irrigation management should and will mitigate the evil to some extent, but experience has proven that it will not obviate the necessity of providing drainage for the surplus water.

Many soils cannot be seeded with the first crop without a waste of water; neither is it practicable in ordinary field irrigation to apply water in such a manner that it will all be taken up by plants or removed by evaporation. Experience also shows that, frequently, subsoils of the most open character, contrary to theory and expectation of irrigators, furnish insufficient natural drainage for land which is copiously irrigated.

Farms are usually injured by the irrigation of the higher levels, the surplus of which passes to lands occupying lower levels. Over-saturation is due to the combined work of all irri-

gators who occupy the higher lands of the district, while the injury resulting from this practice may be visited upon a comparatively few land owners, who are obliged to protect their property by the construction of drains, or abandon their fields to such plants as swamp and alkali lands will produce. Whatever reforms may be made in the application of water to lands, it seems quite clear that draining must become a part of the process required in the permanent reclamation of arid lands, and that the principles and practice of drainage are now as essential to agriculture in the arid sections as those of irrigation.

EFFECT OF SURPLUS WATER.

In order to apply an efficient method of draining, the behavior, as well as the effect of surplus water on irrigated land, should be understood.

The water with which we have to deal is hidden from view and its movement is governed by the physical characteristics and conditions of the underlying earth. Two principles bearing upon the problem may be regarded as established. First, water moves through the earth in obedience to the law of gravity, modified by the condition of earth particles. Second, it does not appear at the surface until the earth below is filled with water. If the irrigated tract is a plain with little slope, the earth will fill quite uniformly; but even with a slope as slight as three feet per mile, the swamped land will first appear at the lower edge of the slope and then creep back and up the slope for several miles if the surface grade continues slight. In case the land where the water gathers is a basin, tule swamps and, in many instances, lakes of considerable extent will form and become a feature of the country. These frequently have been utilized as supplementary sources of irrigation supply, in which capacity they become useful to districts where water is scarce.

Hard-pan, as found in many of the irrigated soils, is a stratum of rock, some kinds of which are slowly soluble in water, but others resist its action. It is not persistent but occurs at irregular intervals and is sometimes found in disconnected layers at varying depths. The effect of hard-pan is to deflect soil water from its vertical course, bringing it near the surface in some places and allowing it to drop away in others. It forms a series

of shelves, which modify the passage of water but are not sufficiently continuous to prevent the water from filling up the lower depth of earth.

Strata of clay and unweathered shale occur below the surface, forming crevices and conduits throughout the soil which lead water along lines often difficult to locate and trace. The effect of such formations is to concentrate water at some lower level, where it suddenly reveals its location by saturating the surface soil until it becomes a bog, or, possibly, prior to saturating the surface, it has brought alkali to the soil in such quantities as to burn out every growing crop.

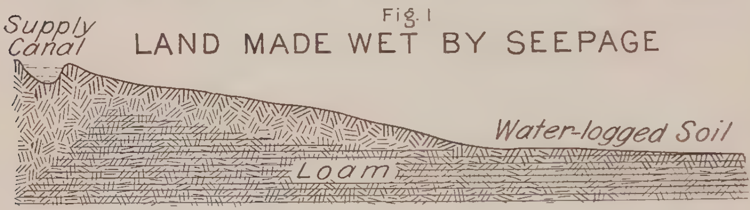
Soils are water-logged from the lower depths upward. The upward movement of the water is slow or rapid according to the facilities which the under-earth has for natural drainage, and the volume of water which is used in irrigating land tributary to the water-logged area. In some sections of the more level class the water line fluctuates between quite wide limits, approaching to within one foot of the surface at the height of the irrigating season, and dropping to a depth of eight feet below during the winter season, after water has been shut out of the canals and all irrigation suspended during the fall and winter months. The process of seeping is illustrated in Fig. 1.

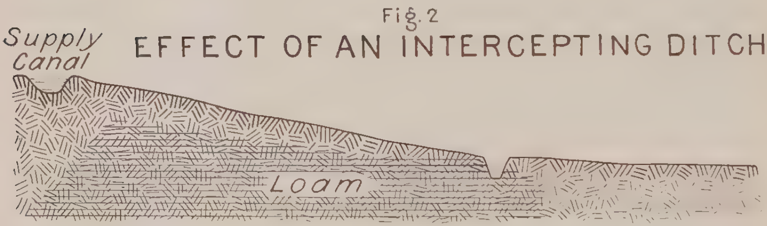
Where the adjoining higher land has a considerable slope, it is not an uncommon occurrence for the soil water-table to begin to rise, and continue to ascend until the middle of the irrigation season, when it covers the surface and flows away, if a surface drain has been provided, or forms a pond of varying depth, if no such outlet is at hand. These are some of the many manifestations of the water which escapes from irrigated land.

ALKALI RESULTING FROM OVER-SATURATION.

There is a more serious effect which frequently works greater harm to irrigated land, and is a close companion of water-logging. Excess of water in the soil dissolves minerals which are soluble in cold water, some of which are injurious to cultivated crops. The minerals or salts which are most injurious and prevalent, are those known to the chemist as sodium chloride, calcium chloride, sodium sulphate, magnesium sulphate and sodium carbonate. When soil water which is charged with one or more of

these salts comes near the surface evaporation takes place, and the salts, being solids, are left in the soil and continue to accumulate in quantity as long as the supply is brought to the surface. The approach of alkali is indicated by the blighting of the plants here and there, followed later by the destruction of all vegetation. In case of an excess of sulphate, the soil finally becomes covered with a white crust, and sometimes with a white powder, several inches in thickness, which remains until rain reduces it to a soluble form, only to appear again during the rainless season.





INTERCEPTING DRAINS.

The method of coping with this growing evil is based on simple principles, but their successful application depends largely upon the skill of the engineer in divining the source and understanding the behavior of underground water. Since water percolates down the slope through the lower horizon of the soil until it reaches an area with less slope and then appears at the surface, the rational way of preventing the saturation of the lower ground under such conditions is to place a drain in such a way as to intercept the water before it reaches the land on the lower level. This is called the method of intercepting drains and is the basic principle of drainage of irrigated lands. (See Fig. 2.)

The location of such drains should be on the upper side of and along the border of the water-logged area, provided that upon investigation the source of the water is found to be the leakage of canals or the waste from irrigated land. Frequently the soil is underlaid with gravel, sand or stratified shale which permits the ready percolation of water down the slope. A change in the slope or in the physical character of the earth will check the flow. The intercepting drain should be placed at this line, which usually extends parallel to the course of the supply canal. It collects the flow and conducts it to the outlet because the resistance to flow in the drain is less than in the soil from which it has been diverted. The drain employed may be an open trench or a covered drain, the choice depending on the volume of water to be collected. Where the source is the leakage from a canal or from a large tract of gravel bottom land, an open canal is necessary. Usually, however, covered drains may and should be used, provided outlets can be secured without constructing drains more than one mile long.

The depth of an intercepting drain is as important as the alignment, for unless the bottom of the drain is placed as low as the plane of the flow through the soil, water will not be intercepted but will pass under the drain and appear on the land farther down the slope. A drain improperly located as to depth or alignment will render no service whatever, as has been frequently demonstrated in practice.

GENERAL INVESTIGATIONS.

The drains cannot be successfully located until the character of the earth formation and level of the ground water have been ascertained by a survey of the subsoil. This is accomplished by means of borings, or, in some cases, by open pits in connection with a system of levels, which should be made frequently in order to locate the water-bearing and water-deflecting formations, and so enable the engineer to trace the underflow and, particularly, to determine upward pressure due to static head which the water exerts on the soil. Borings will reveal several facts which are essential to the location of efficient drains, some of which are the following: (a) The depth to a hard bottom which prevents water from descending to a lower level; (b) the existence of hard-pan

which deflects the movement of soil water, and of layers of shale or rock with crevices which conduct or concentrate water; (c) the presence and position of gravel, sand and clay, together with the position of the water table in them.

The location of the borings, the elevation of the surface and of the water level, and the position and character of the modifying factors beneath the surface at those points should be determined by survey. A careful study should then be made of the data which have been secured in this way, and a theory evolved by the engineer regarding the source, behavior and move-

Fig. 3
RELIEF WELL AND DITCH

Fig. 4
GRAVEL COLLECTING PIT
IN CONNECTION WITH TILEDRAIN

ment of the ground water which water-logs the tract of land he desires to drain. The drains should then be located in accordance with that theory. One principle, simple in itself, but not always easy to apply, is to place the drain where the water enters and begins to accumulate on the saturated tract.

RELIEF WELLS.

As has been observed, water may come to the land from a deep subsoil reservoir. Such water being under pressure produced by water occupying a greater altitude, causes it to press upward continuously on the soil of the lower levels. It may be

impracticable to place the intercepting drain sufficiently deep to reach the underflow and cut off the pressure or supply. Under such conditions, the drains should be supplemented by relief wells, which should be sunk well into the water bearing materials. In case of an open ditch, the well should be placed on the upper side and be connected with the ditch by a side pipe of 8-inch drain tile, as illustrated in Fig. 3. Where the main drain is a pipe or a box, the same plan may be followed. (See Fig. 5.) Where the soil is all loam, the effective depth of an underdrain is sometimes successfully increased by a pit made directly beneath the drain and filled with coarse gravel up to the established grade upon which the drain is laid. The latter method is also used with good results by placing the relief pits at intervals under the drain, as represented in Fig. 4.

The well gives a free and unobstructed conduit, which, under the pressure of water occupying a higher elevation, rises in the well and flows away by gravity through the drain with which it is connected. The action is the same as that of an artesian well. Wells may be located at regular intervals of two hundred or three hundred feet along the line of the drain, or at such places as by examination have been found to deliver water to the land from a depth greater than that at which it was found practicable to place drains. It may be necessary to sink the relief wells to a depth of eight to sixteen feet. In all cases, they should have a free connection with a well constructed drain.

The construction of wells will necessarily vary with the conditions of the ground and the material which is available. In practice, they are made of wooden boxes four feet square, which are lowered in sections as the earth inside of them is excavated and removed. Land that requires draining is usually in an unstable condition, and, consequently, drains and their accessories are difficult to make. Wells are sometimes made with a well-boring tool which will permit a casing of clay sewer pipe to follow.

The relief well is quite wide in its application. It is successfully used as a drainage adjunct in most localities where a tract of irrigated land has a considerable slope toward a flat that has become water-logged, particularly where the higher land is underlaid with gravel or sand. A few wells placed near the line

marking the divide between the wet and dry land, and furnished with an outlet into a drain pipe, will frequently drain a large tract of low land by cutting off the supply which causes the water-logging, having the same effect as the intercepting drain which cuts off water which has its source in a higher level. (See plan and profile, Fig. 5.)

Information required for the location of such wells can be best secured by a series of borings, which should be made in

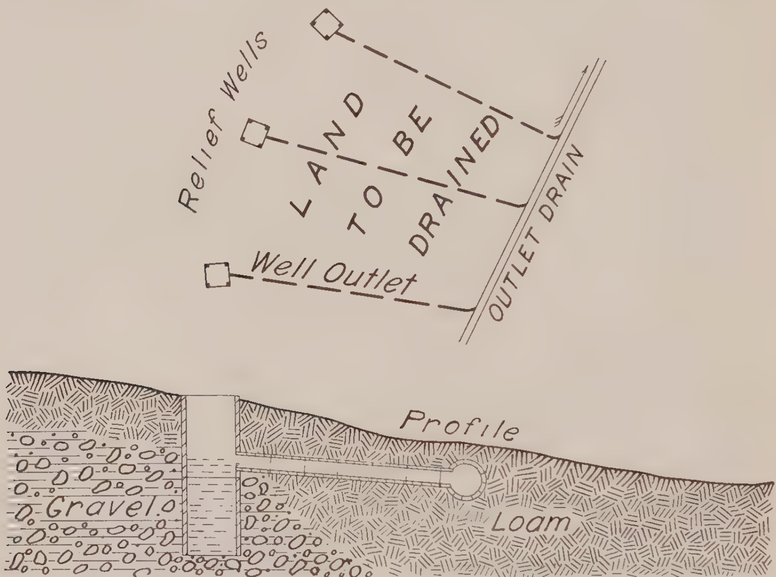


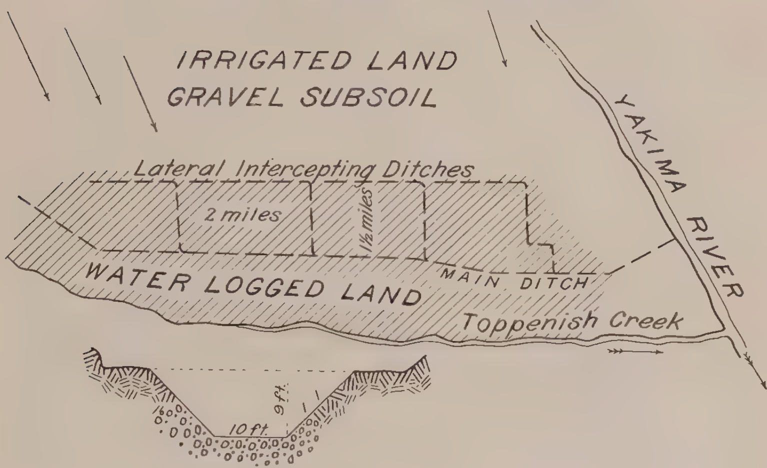
Fig. 5
DRAINAGE BY RELIEF WELLS

connection with a careful inspection of surface conditions. When the proper place for the wells has been ascertained, it remains for the engineer to devise outlet drains for the wells. Under some conditions, a separate drain, which should be covered, may be laid for each well, and discharge into some drainage ditch or into an irrigation lateral occupying a lower level. In others, several wells may be connected with one drain, the connections being made by means of a pipe leading from each well to the drain.

TREATMENT OF LEVEL LANDS.

The treatment of land which is more nearly level, that is, with a slope of three to five feet per mile, differs, in some respects, from that having greater slope. The process of water-logging is the same, in that the lands on the lower levels show seepage first, but the water enters the soil under a relatively small head, fills the lower depths of the soil from the bottom toward the surface, gradually rising until the water plane reaches sufficiently near

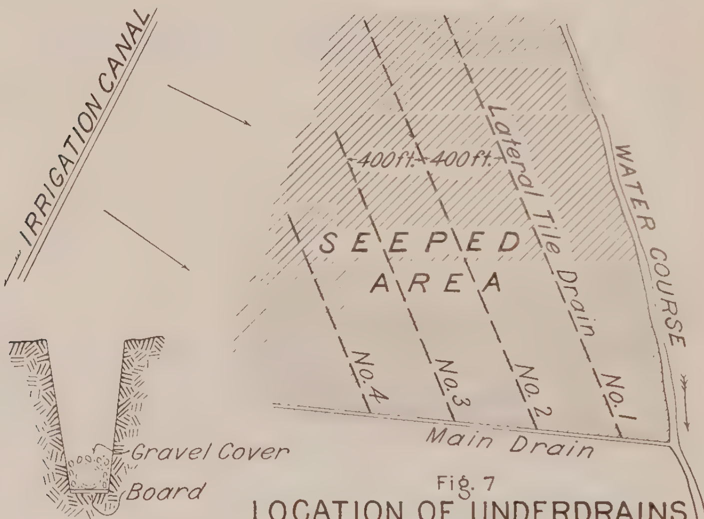
Fig. 6
SKETCH SHOWING PLAN
OF DRAINING 40,000 ACRES ON
THE YAKIMA INDIAN RESERVATION



Type of Main Ditch

the surface to injure vegetation. The water plane fluctuates with the quantity of water used in irrigating the land during the growing season. The problem is to reduce the height of the water table so that it will not come nearer to the surface than four feet. Where such conditions prevail, the pressure of the water upward is not sufficient to prevent its flow laterally into under-drains which are laid at a depth of six feet. Such drains are most effective when laid diagonally across the slope, passing under irrigation laterals where necessary to reach an outlet. At points where tile drains pass under irrigation ditches the joints should

be well cemented. (See Fig. 7.) The attempt to drain seeped land by laying drains up and down the greatest slope of surface has usually proved unsuccessful, except where examination of the structure of the subsoil shows that the flow of water is concentrated along lines which coincide with the surface slope. In such cases, drains laid along the line of the greatest surface slope are effective. The system should be laid out so that the drains will interfere as little as possible with the irrigation laterals. The engineer must determine whether or not intercepting drains or



Method of Securing Tile in Saturated Ground

Fig. 7
LOCATION OF UNDERDRAINS ON FLAT LAND

relief wells will aid in draining land of this character. If the irrigation canal which supplies the tract leaks to any appreciable extent, a tile drain laid about fifty or one hundred feet distant from and parallel with the canal, and five or six feet deep, will materially diminish the amount of water that enters the subsoil.

DEPTH OF DRAINS.

A depth of six and, sometimes, eight feet is required to make drains effective. Drains three or three and one-half feet deep are

useless for reclaiming water-logged lands because of the strong capillarity of the soil which will bring water charged with salts to the surface from a depth of three feet, and, also, because plants in an irrigated soil require a depth of at least four feet of good moist soil for a thrifty growth. The water which comes from below is cold and stagnant and is particularly deleterious to plant life. In order to control the water which is continually pressing laterally and upward through the soil, drains should generally be six feet, and never less than five feet deep; and drains placed ten feet deep are sometimes required. This fact has been so thoroughly demonstrated that it may be regarded as a cardinal principle in the reclamation of seeped lands.

QUANTITY OF WATER TO BE REMOVED.

From the discussion of the manner in which land becomes water-logged, it will be seen that the volume of flow for which drains must be provided will depend upon several factors. The water-logged area is but the receptacle of surplus water which comes from a large area of irrigated land, increased, possibly, by leakage from canals. Over-irrigation may be the practice on some parts, and moderate and careful irrigation on others. Canals may have leaks which contribute a considerable but unknown volume of water that finally reaches the low land.

The area which contributes the water should be ascertained as nearly as possible by the preliminary survey, together with the character of land and the amount of water applied to it, and the facts used as a basis for estimating the quantity of water that flows into the water-logged area which it is proposed to drain.

Experience in draining various classes of land has developed the following data upon this subject: Capacity of main or trunk line drains where the contributing area is level, 2.5 cubic feet per second per square mile. Lands with gravel or shale bottom having good slopes, 3 to 5 cubic feet per second per square mile, or one cubic foot per second for 200 to 125 acres. The main drains on the Yakima Indian Reservation, before referred to, deliver about 3.2 second feet per square mile. (See Fig. 6.) Observations on quite a wide range of irrigated territory indicate that after land has been brought to a condition where drainage is required, from one-third to one-half of the water applied during

the irrigation season should be removed by drains if the land is to be maintained in a productive condition.

INTERIOR DRAINS.

It is quite frequently, though not always, the case that cutting off the water from saturated land by intercepting drains and wells will effectually dry it. As a rule, however, its natural under-drainage is not sufficient to take care of the surplus of irrigation, which is applied directly to the land, and a few under-drains must be laid where most needed to keep the land dry to the proper depth. Where the land is uniformly level, it may be necessary to place the drains at a uniform distance of three hundred to five hundred feet apart, at a depth of four feet to five feet. Such care should be taken in locating that the fewest drains that will serve the purpose should be used.

KIND AND GRADE OF DRAINS.

Open ditches are required for large outlets, and are made by power dredges of the dry-land type. Their maintenance is a large and continuous expense, because of the quantity of rolling weeds and thistles which lodge in the ditches and which, with the silt they gather, seriously obstruct the flow. Were it not for the expense, large clay or cement pipes would be used instead of many of the open ditches it now seems necessary to construct.

The grade for open ditches should be, if possible, not less than three feet per mile, though natural surface slopes will necessarily largely dictate the grades. The flow is never very rapid in such ditches, so that erosion does not occur where there is little grade. The sides cave down easily in most soils, so that side slopes of one to one should be given to the ditches, or else they should be excavated wide enough to allow the sides to cave and take a position of rest without reducing the bottom width beyond the limit required.

The covered drain should be used wherever it is practicable to do so. The round clay pipe or the well-made cement pipe is the ideal kind of drain. They are made in lengths of one and two feet, without sockets, and are joined end to end in a smoothly graded trench. Water enters the drain through the joints. Pipes of less than six inches in diameter should rarely be used, nor

should they be laid on grades less than fifteen one-hundredths feet per one hundred feet. Mains from ten to fifteen inches in diameter may be required in some cases. The construction of the drains should be accurate throughout, though this may, in some cases, be a difficult and expensive operation. If laid in gravel or clay, the joints should be left open a trifle, not to exceed one-eighth inch, for the more ready entrance of water. If the earth is sandy or soft mud, it may be necessary to lay the tile on a rack made of two strips of one inch board, and to cover the joints of tile with gravel two inches thick, to prevent the mud and sand from choking the drains.

Where drain pipes are not practicable on account of their cost, lumber box drains may be substituted. Small drains are usually made of one inch boards, the sides being six inches and the top and bottom eight inches, making a drain 6″ by 6″ inside. If it is to be laid in gravel, the bottom board may be omitted and cross cleats substituted, making an open bottom drain which is very effective. If the solid bottom is used, the bottom board should be separated from the sides by one-half inch blocks, thereby making a crevice for the entrance of water. When drains of larger size are used, planks one and one-half inches or two inches thick should be used. Lumber drains are subject to decay if not constantly wet, so that the length of time they will last is always uncertain.

SILT-WELLS OR SAND-TRAPS.

When drains pass through sand or wet, soft material, more or less silt will find its way into the drain. In such cases, the silt-well is an important adjunct and should be placed in the line of the drain at intervals of four hundred or five hundred feet, and, particularly, at points where the grade changes. They are usually boxes four feet square, made of two-inch plank with 2″ by 4″ corner pieces. The box extends two feet below the bottom of the drains. The inflow pipe enters the box and drops the sand it carries and the outflow pipe being placed a little lower than the inflow, takes the water after the silt has been deposited. The sand is removed from the box as often as it may be necessary and the drains can thus be maintained in an efficient working condition.

DRAINAGE BY PUMPS.

Gravity outlets or drains are sometimes difficult to secure because the land to be drained is so distant from a natural water-course that the construction of an artificial one is impracticable. In such cases, it is feasible to lead the drainage water of a field or farm into a sump or well by means of underdrains, install a centrifugal pump and lift the water into an irrigation lateral ditch. The sump should be located near an irrigation lateral, into which the water raised by the pump can be discharged. It should, ordinarily, be eight feet square and ten feet deep. A three-inch pump operated by a gas engine will keep the water down in the well for the drainage of five hundred acres or less. The plan is practicable and possesses the advantage of being applied by one or more land owners in draining land which has no gravity outlet that can be reached within a reasonable cost, and, also, where it is impossible to secure the cooperation of landowners, under the provisions of state drainage laws, in the construction of suitable outlets.

RESULTS OF DRAINING.

The effect of water-logging is sometimes limited to the injury from saturation alone, but more often includes both that due to over-saturation and to accumulated alkali. Draining will remove both; but when the land has become strongly alkaline, supplementary treatment will often be required to complete the reclamation.

The effect of drains which are well located and constructed will be marked, and almost immediate upon the completion of the work. The soil which has been sub-irrigated and wet will require surface irrigation. If alkali has only recently appeared, a few copious irrigations will remove it, and the land will be restored to its former use and productiveness. The open ditches will require constant care and frequent clearing, and sand which accumulates in the bottom of the silt wells must be removed from time to time.

In case alkali has accumulated in the soil in such quantities that it will not readily yield to careful irrigation, it will be necessary to flood and cultivate the land alternately for the purpose of reducing the salts to a solution, in which form they will pass into

the soil and be removed with the drainage. If the land is strong with alkali, a system of check dikes will be required to retain the flood water upon the land until it covers the surface. It will be necessary to have drains under the alkaline spots of the field, and under the entire field, at intervals of from three hundred feet to five hundred feet, if the entire tract of land is quite uniformly affected.

Experience teaches that when the land becomes dry on the surface after flooding, it should be cultivated in order to make it more permeable and to expose new soil surfaces when water is again applied. Such treatment may be required during one or two seasons, before the land is reclaimed, the length of time depending entirely upon the kind of soil, and the quantity and also the kind of alkali with which it is charged.

To ascertain whether the land is reclaimed, seeds of plants which are somewhat alkali resistant, such as barley, sweet clover, or sugar beets should be planted as a test. The land should be irrigated quite freely until it has been so fully freed from alkali that it will grow any crop desired.

This most serious evil may be obviated entirely if drains are installed as soon as the land begins to show injury either from seepage or alkali. The work should be done promptly, because the longer it is neglected, the more expensive it will be to construct the needed drains, and the more difficult will it be to correct the effects of seepage. When lands have once been productive under irrigation, it is reasonably certain that when the cause of their failure has been removed, they will again respond bountifully to the labor and care of their owner.

ENGINEERING FEATURES OF THE WORK.

The engineering required in the successful drainage of irrigated lands is so closely connected with construction methods that the engineer should be thoroughly conversant with both, and, particularly, with the difficulties that will be encountered in executing the proper plan. Since he must deal with construction as well as design, he must make a careful study of the features of each case and devise and recommend the method best adapted to the situation. The levels, borings and pits, before described, and particulars regarding the area and character of the irrigated land

lying above the tract to be drained, together with the amount of water usually applied to it, are essential preliminary data.

Drains should be staked out and grades indicated in the ordinary way. It will be well to reserve the right to change the location of accessories, such as relief wells and sand traps, for unforeseen underground conditions frequently arise as construction proceeds which make it advisable to modify the plans in some particulars after actual work has begun. The extent to which machines and hand labor, respectively, may be employed will be a factor in the plans and estimates in this kind of reclamation. If drains cannot be properly located, no attempt should be made to construct them.

This subject will require the attention of practical engineers in the United States as long as lands continue to be irrigated. Drainage is so closely connected with irrigation in the reclamation of arid lands that the latter should not be considered without the former. With the wide differences existing in the physical and surface character of lands, and in the methods of applying water to them, plans made and executed in accordance with careful and intelligent studies of the several cases are absolutely essential to the preservation of our irrigated lands to usefulness.

Contrary to the theory advanced by some engineers, drains cannot be provided for lands in connection with the design of irrigation works, except to the extent of keeping all natural drainage channels free from obstruction by the works of irrigation. The changes produced in the subsoil by the application of water cannot be predicted in advance with any certainty. Irrigators must watch for the signs of seepage and alkali, and when they appear, make the necessary investigations and apply the remedy without delay.

DISCUSSION

Mr. Duryea. **Mr. Edwin Duryea, Jr.,*** M. Am. Soc. C. E. (by letter), stated that Mr. Elliott's long experience as Chief of Drainage Investigations, U. S. Department of Agriculture, gives great weight and value to his statements of experience and opinion.

His warning against the injury which will result to irrigated lands by swamping and rise of alkali from over-irrigation should receive serious consideration. His statement that more than a million acres in the

* Cons. Engr., San Francisco, Calif.

Mr. Duryea.

United States are already so injured shows this danger to be a more general and important one than usually is realized. It is to be regretted that new irrigation projects seem unable to profit from the mistakes and abuses of the old, and that injury to more or less of the lands of new developments from over-irrigation seems to be the rule rather than the exception.

Some injury to some land probably is inevitable with all large irrigation developments, but it is believed that the greater proportion of such injuries are due to a selfish desire by those who have had insufficient or no irrigation water in the past to secure thereafter as much water as possible, without any regard to the real needs of the crops. Most new irrigators with water are like a small child with a large box of candy—and take so much that it is harmful.

Mr. Elliott gives three general conclusions relating to drainage which, in view of his ample experience, are of the greatest interest and practical importance:

(a) That the reclamation of arid lands by irrigation should not be considered except in connection with drainage soon to follow;

(b) That drainage systems cannot adequately be located and provided in connection with the construction of irrigation systems, beyond the keeping of all natural drainage channels unobstructed—since the changes in the permeability, etc., of the subsoil caused by water cannot be predicted with any certainty in advance of its application;

(c) That when lands which once have been productive under irrigation have been injured by swamping or alkali, it is reasonably certain that they can be restored to full value by the removal of the cause of their injury.

Paper No. 40

ITALIAN IRRIGATION.

By

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GENERAL INFORMATION.

Climatic Conditions. The climatic conditions of Italy might be compared, in general terms, and with only some few exceptions, with those prevailing in the Western States of America, called the "semi-arid" regions; that is, where there is a rather excessive proportion of sunshine—about 2700 hours per year—and a decided deficiency of moisture, owing to the reduced rainfall, aggravated by the fact of its irregularity.

The rainfall averages about 36 inches per annum in the northern provinces of Italy—especially in the watershed of the River Po—and decreases southwards, amounting to about 20 inches in Apulia and Calabria, and to even less than this in other places—as for instance, in Catania and other regions of Sicily, where it amounts to only 15 inches in the average year and less than that amount in years of drought, which are not rare.

Besides its small value, the rainfall is not distributed evenly during the whole year—as for instance, it is in Central Europe, especially in England, Holland and Denmark,—but it is governed by what the meteorologists call the "Mediterranean régime"; that is, the rainy season generally begins in October and practically ceases in April, when the warm and dry season begins and a long spell of hot weather follows, with practically no rain for 4 to 5 months. Only very limited dews fall at night, so this period instead of being the most active for agricultural

pursuits—thanks to the abundance of sunshine—is, on the contrary, a period when vegetation falls almost into lethargy. The herbaceous plants dry up, the natural grasses disappear from the plains, and even the trees suffer more or less from the effects of the lack of moisture both in the soil and air.

Necessity for Irrigation. However, if we travel along the plains of Piedmont and Lombardy, we can see the most exuberant green meadows of trefoil and lucerne, even during July or August—the hottest months in Italy—and all along the coasts of Ligury, Campania, Calabria and Sicily we can admire orange groves, beautiful orchards and vegetable gardens, and also large tracts of land planted with flowers for industrial purposes; all very prosperous all the year round.

This most satisfactory change in the natural conditions of the land is brought about by the artificial distribution of water, at the proper moment, in the exact quantity needed by each class of plant—that is, by scientific irrigation. Irrigation is an art that, in Italy, has been practised from time immemorial (from the time of the Etruscans and the Romans), and has been brought down through the Middle Ages to its present state of perfection.

Thanks to irrigation, the waste, sandy plains of Piedmont and Lombardy—where only stunted grass and wild shrubs could live in normal conditions—were transformed into rich rice fields and prosperous meadows, which give as many as 7 or 8 cuttings of lucerne per year. It is to irrigation that the vegetable gardens all along the Tyrrenian Coast and the orange groves in Ligury, Sardinia and Sicily owe their existence and were so abundant and beautiful that Goethe, even in his time, called Italy "the land where the orange blooms".

How Italian Experience Can Be Useful to Americans. From these general considerations it can be seen that the climatic conditions of Italy are very similar to those of many of the Western States of America, especially of California, which is similar in every respect (even to the doubtful privilege of seismic movements) to the most prosperous regions of Italy. So it may be of interest to Americans, and to others interested in agriculture, to know how the Italians, with the help of irrigation, manage to get the best out of their native country, which,

having neither mines nor forests to speak of, depends for its principal revenue upon the cultivation of the land and the industrial treatment of its products, such as oil, wine, spun silk, and the like.

Benefits of Irrigation. It is the firm opinion of all Italians that irrigation gives most beneficial results, not only from the private point of view of the proprietor—who gets a revenue double, and sometimes even greater, from his land when treated by irrigation—but also from the public point of view; as the most prosperous agricultural districts of Italy—where the population, although very dense, is content—are those where irrigation has been practised for centuries. In regions formerly suffering from great emigration—owing to the natural increase of population, which brought about some poverty—the evil was cured as soon as irrigation was introduced; emigration soon diminished and then ceased almost completely, and this owing to the larger crops raised and to the increased prosperity of these districts.

Irrigation, besides acting as a great stimulus to vegetation in ordinary years, saves the crops from failure during periods of drought. So, besides increasing the normal production of the soil, irrigation acts as an insurance against complete loss of crops in bad years; and the farmers can always rely on the certainty of gathering a crop that pays for all expenses, leaving a small profit even in bad seasons, and securing a large profit during good years.

Speaking broadly, irrigation doubles, or more than doubles, the average production of the land, and allows for the cultivation of higher-priced products; thus it gives a profit more than double that obtained from non-irrigated land. The rent paid by farmers in the Roman Campagna for ordinary grazing land varies from \$6 to \$10 per acre per year, whilst when irrigated, the rent increases from \$14 to \$25, and if cultivated with Indian corn, it pays even more. In Sicily, while the rent of good land planted with olives or vines varies from \$20 to \$30 per acre, when irrigated and planted with oranges or early vegetables it increases even up to \$100 to \$120 per year per acre, leaving still a sufficient margin for a family of cultivators to live fairly well, even on such a small surface as two acres of land.

Fig. 1. Italian Irrigation Systems.

Importance of Italian Irrigation. The whole surface of Italy (Fig. 1) measures 286,682 square kilometres,* and of these, 51,674 sq. km., or about 19%, are glaciers, rocks, sand dunes and such like lands unfit for vegetation. Of the remaining area, 30% is composed of forests, 23% of artificial meadows or natural grazing lands, and 28% is cultivated. These cultivated lands

* 1 square kilometre is equal to 247 acres = 0.39 sq. mi.

measure 80,862 square kilometres (nearly 20 million acres), and of them, 14,000 square kilometres (3,458,000 acres), or about 17% of the cultivated surface, are irrigated.

Of these 14,000 sq. km., 12,000 sq. km. (2,961,000 acres) lie in Northern Italy, between the Alps and the Apennines, in the flat valley of the River Po, where rivers are more numerous and irrigation is easier. The other 2,000 sq. km. (494,000 acres) are in Southern Italy, where water is very scarce and has either to be raised from underground sources or collected in artificial reservoirs.

In this way, agriculture with the aid of irrigation, even when applied to a poor soil, leaves a fair margin of profit; sufficient to be invested in further improvements of the land or of the towns, or in other works of comfort or of beauty. And this process, repeated almost continuously for 25 centuries—that is, from the time of the Etruscans and the Romans, through the Middle Ages, up to our days—has made Italy what she is now, the land of arts, of music, of monuments, notwithstanding all the wars and vicissitudes she has gone through.

Irrigation is the principal factor in the success of Italian agriculture and in the present progress of the Nation; so it is important to know how it is applied, that is, how the water is provided and how it is distributed over fields; and the results. technical and economical, given by irrigation.

HOW THE WATER FOR IRRIGATION IS PROVIDED.

(a) Underground Water, Raised from Wells. When only small quantities of water are required—as for the cultivation of flowers for industrial purposes, or for orange groves or similar products of high commercial value—the water is generally obtained from wells dug in the sandy subsoil at the foot of the hills and around the coasts, and is raised either by very primitive means, such as the "water buckets" (*cicogna,* or *altalena*), worked by hand, in a manner very similar to the Egyptian *shadouf* (Fig. 2), that can lift the water through a height of 2 to 4 metres (7 to 14 feet); or with *norias,* or rosary pumps, formed by two ropes or chains with buckets every foot, moved by animals, raising the water up to a height of 5 or 6 metres (16 to

20 feet) and sometimes up to 10 or 12 metres (33 to 39 feet). These contrivances are very common, especially in Southern Italy. In the North, on the other hand, small, but very modern, centrifugal pumps driven by oil or electric motors (generally from about 2 to 5 hp.) are more in use, lifting the water from 10 to 12 metres (33 to 39 feet), and occasionally up to 40 metres (130 feet). These can be seen in large numbers along the Ligurian Riviera and in many parts of the Valley of the Po, where there

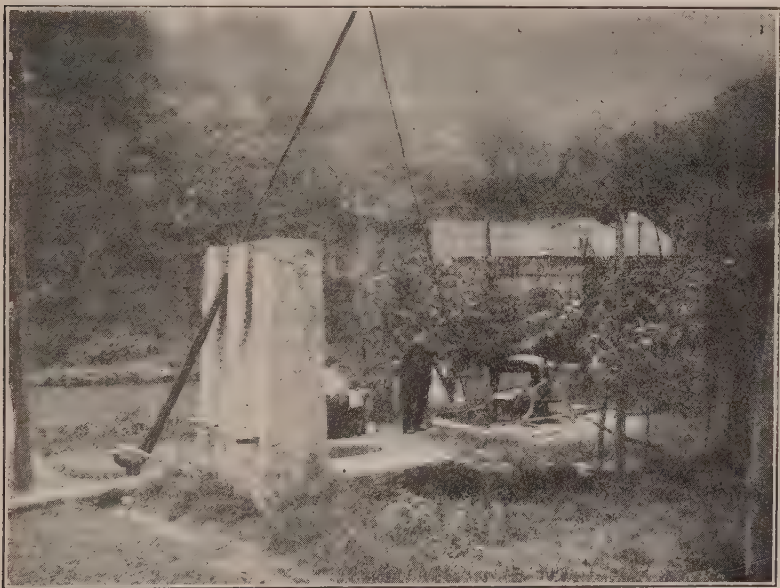

Fig. 2. Irrigation Well with "Cicogna" (Bucket Lift) and "Noria".

are many hydro-electric plants that during the daytime sell the current at very low rates.

The cost of water raised by manual labor varies from francs 0.10 to 0.15 per cubic metre ($0.09 to 0.14 per 1000 gallons) for lifts between 2 and 4 metres (7 to 14 feet); if raised by *norias* moved by animals, the cost varies from francs 0.04 to 0.10 per cubic metre ($0.04 to $0.09 per 1000 gallons), according to the lift—from 6 to 12 metres (20 to 39 feet). If raised by oil engines, the average is francs 0.04 ($0.04), and by electric motors, francs 0.02 per cubic metre ($0.02 per 1000 gallons) for lifts up to 10

to 12 metres (33 to 39 feet); and it reaches as high as francs 0.10 to 0.15 ($0.09 to $0.14 per 1000 gallons) for lifts up to 40 metres (about 130 feet).

Although the cost of the water is so great—and it is not unusual to pay from francs 0.25 to 0.30 per cubic metre ($0.24 to $0.28 per 1000 gallons), and sometimes even as high as francs 0.40 per cubic metre ($0.36 per 1000 gallons)—still the irrigation is done with such great care and minute economy that only from 2000 to 3000 cubic metres are required per year per hectare* (25,200 to 41,600 cubic feet per acre); and the products grown in this way—such as flowers, oranges, early vegetables, special classes of prime fruits, etc.—realize such high prices that this expenditure is fully justified and leaves a very fair profit to the growers of all these delicacies, which find a ready market in Central and Northern Europe, especially during the winter months.

The yearly rent of a good orange grove of Sicily varies from 1500 to 2000 francs, and sometimes even amounts to 3000 francs per hectare ($150 to $270 per acre) per year; whilst the same land not irrigated and only in condition to be cultivated with vines, olives, etc., pays rents ranging from about 160 to 250 francs per hectare ($12 to $20 per acre). All the good plots of land from Taggia to San Remo in the Ligurian Riviera that are cultivated with violets, roses, and especially carnations, or *garofani*, give a net yearly revenue of from 5000 to 10,000 francs per hectare (up to $800 per acre). These, however, are especially favored strips of land in a region of perpetual spring, where the land produces all the year round and the skilled gardeners are untiring in their labour.

(b) Water Derived from Infiltration Tunnels. Some parts of the Roman Compagna, and also around Naples, are literally honeycombed with a network of narrow tunnels† (a great many of Etruscan and Roman origin are still in good working order) that collect and bring to the surface at a lower level the rain water that percolates through the fissured volcanic formation of these regions. These tunnels are simply excavated through the

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* A hectare equals 2.47 acres.

† D'Ossat, "I cunicoli della Compagna Romana", Atti Società Ingegneri, Roma, 1890.

"tufa" without any linings. Their cross-section is only just sufficient for a man to pass through; generally it is 1 foot 8 inches by 6 feet, and in some cases even only 1 foot 2 inches by 5 feet 6 inches. At every 50 to 100 yards there is a ventilating shaft, which is used also for repairs.

Many similar tunnels also exist in other regions of Italy, where the ground is composed of "conglomerate", and are called *pozzi allacciati*,* or "connected wells". These serve for irrigating small plots of land. The most interesting, however, are the "infiltration tunnels" (*gallerie filtranti*) of Southern Italy, which play a very important part in the cultivation of oranges, early vegetables and similar high-priced products.

There are some regions, especially in Sicily and Calabria, with large valleys filled with deep deposits of alluvium, which, during the rainy season, become saturated with water, almost forming an underground reservoir. This water percolates slowly in the form of underground drainage. In these cases it is usual to drive a small tunnel† in an oblique direction so as to intercept this underflow, taking advantage of the altimetric conditions and of a fall, generally of 3 in 1000, in the tunnel. The water comes naturally to the surface and can be distributed over the fields at a lower level without need of pumping. These *gallerie filtranti*‡ are often several hundred yards long, have a net internal section (Fig. 3) of 1.8 m. by 0.6 m. (6 ft. by 2 ft.), and are lined with porous masonry, but with an impermeable bottom of concrete. Their cost varies from 75 to 100 francs ($15 to $20) per lineal metre (3 ft. 3 in.). The total cost of such tunnels varies from about 20,000 to 40,000 francs each ($4000 to $8000), and each can deliver from 1000 to 2500 cubic metres (290,000 to 550,000 gallons) of water per day; thus the cost per cubic metre of water is considerably less than that raised by electric power, and a fraction of that raised by animal or manual labour.

One of these infiltration tunnels, at Mazzara,§ delivers 100 litres (22 gallons) per second (Fig. 4) and serves to irrigate

* Luiggi, "I pozzi allacciati dell' Isola di Cipro", Giornale Genio Civile, Roma, 1880.

† Bionda, "Le Gallerie filtranti della Provincia di Messina", Roma, 1908.

‡ Torricelli, "Gallerie filtranti longitudinali", Roma, 1888.

§ Mayer, "L'acqua per irrigazione", Naples, 1914, p. 204.

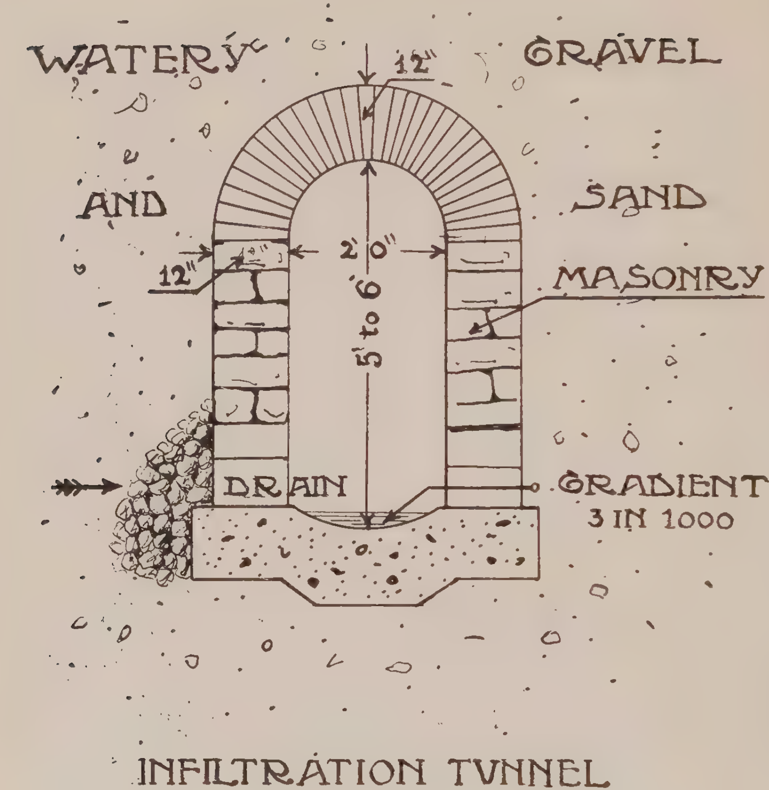


Fig. 3.

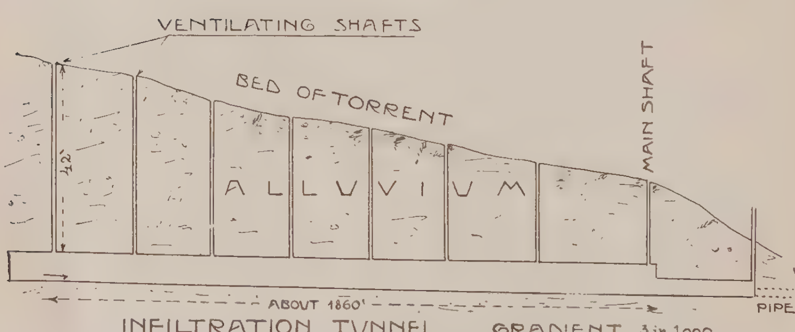


Fig. 4. Infiltration Tunnel at Mazzara, Sicily. Discharge, 23 Gallons per Second.

some 220 hectares (about 500 acres) of orange groves and vegetable gardens; another, the largest in Sicily, at Zappulla, gives nearly double this quantity. As its total cost was 150,000 francs ($30,000), the actual cost of the water is very small indeed, being only the interest on the capital and expenses for the maintenance of the tunnel. Reckoning these at 10% per year, the cost of the water is about francs 0.005 per cubic metre (0.5 cent per 1000 gallons).

In some cases where narrow gorges occur, a sort of underground dam of puddled clay is built across the bed of the torrent so as to stop the underflow; thus the water rises to the surface and can be utilized for irrigation with less cost than for a tunnel. A good example of these subterranean dams (*dighe subalvee*) is at Trabia* in Sicily.

In some parts of Lombardy and in the province of Modena, there are large volumes of water flowing underground from the lakes or the mountains to the River Po; and the altimetric conditions of the ground are such that the water can easily be tapped by ordinary wells, of about 20 or 30 feet diameter, and conveyed by a deep cutting to the surface of the fields at a lower level, thus forming a sort of artificial spring, called *fontanile*,† very similar to, but not to be mistaken for, an artesian well. Some of these *fontanili* give water enough to irrigate several hundred acres of meadow land, called *marcite*, which are considered the most valuable in Italy. As these underground waters have a temperature of about 56° to 60° F., in the winter-time—when the land is covered with snow—these meadows, or *marcite*, being abundantly irrigated with this water, slightly warm, are intensely green, forming a striking contrast in the landscape.

Thanks to the comparative warmth of the water, these specially super-irrigated meadows can give regularly 7, and even 8, cuttings of grass per year, that is, from 80 to 100 tons of lucerne-grass per year per hectare of *marcita*, which is an exceedingly large production.

(c) Storage of Rain-Water by Means of Reservoirs. The irrigation above mentioned is possible only in especially favored localities, and, except in a few cases, the amount of water is

* Capitò, "Dighe subalvee", Giornale Genio Civile, Roma, 1883.

† Lombardini, "I fontanili della Lombardia", Milano, 1863.

generally very small—less than 10 cu. ft. per second. When larger quantities are required, it is better to store up, by means of impounding reservoirs, the rain-water which falls during the winter months, averaging from 36 inches in the North of Italy to 20 inches in the South.

During the warm season, the rainfall is very irregular, scanty and of little benefit to the land.

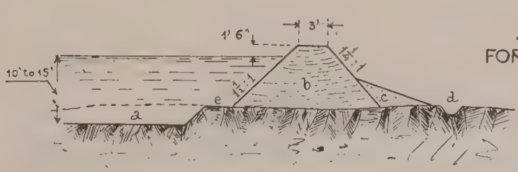
These impounding reservoirs may vary from the modest cistern of some few hundred cubic metres capacity, built of solid masonry, to small ponds or "tanks", called *serbatoi a corona*, of some 20,000 to 100,000 cubic metres (700,000 to 3,500,000 cubic feet) capacity; or even to large reservoirs or artificial lakes of many millions of cubic metres capacity.

For instance, one of the latter, now in construction on the River Tirso in Sardinia, with a dam 55 m. (180 ft.) high, will impound 350 million cubic metres (12,300 million cubic feet) of water, and will be, for the present, the largest in Europe. It will, however, be surpassed by two similar reservoirs soon to be commenced, one on the Bradano (dam 60 metres, or 200 feet, high) and the other on the Fortore (dam 75 metres, or 250 feet, high) in Apulia, and by a third, on the Simeto (dam 50 metres, or 170 feet, high) in Sicily, which will be able to store up respectively 13,840 million, 13,180 million and 12,150 million cubic feet of rain-water. Thus the winter floods in those regions will be diminished, and the water stored up for irrigation will be distributed on the plains traversed by these rivers, which, though now almost a curse, when regulated, will be a blessing to the farmers.

(d) Small Reservoirs or "Tanks". These small, artificial "tanks", as they are called in India, or *serbatoi a corona*,* are numerous in the provinces of Piacenza and Parma. They are formed by enclosing some natural depression of very bad clayey land with earthen dykes 12 to 16 feet high, and from one to even two miles long, provided with an outlet of masonry closed by a sluice gate. Usually, they cover an area of from 4 to 5 hectares (about 9 to 11 acres) with water from 2.50 to 3.50 metres (8 to 12 feet) deep, sufficient to irrigate sparingly, on the average,

* Raineri, "I Serbatoi a corona", Federazione Agricola Italiana, Piacenza, 1907.

about 8 to 9 hectares (17 to 20 acres) of meadows, at the rate of about 7000 cubic metres of water per hectare (100,000 cu. ft. per acre) per year. (Figs. 5 and 6.) This corresponds to a depth of water of about 0.70 m. (28 inches) distributed over the land during the 5 to 7 months of dry season. This water is applied in "rotations" of about 40,000 to 50,000 gallons per acre every 12 to 14 days, and the cost of irrigation amounts to about 90 to 100 francs per hectare per year ($8 to $9 per acre), or at the rate of francs 0.012 per cubic metre (one cent per 1000 gallons), which is notably less than that of the water raised from underground.



DYKE
FOR SMALL IMPOUNDING
RESERVOIRS

a = ESCAVATION FOR DYKE

b = DYKE MADE OF SELECTED MATERIAL WELL RAMMED IN CURVED LAYERS

c = REINFORCEMENT MADE WITH MATERIAL NOT GOOD FOR DYKE

d = SMALL DITCH TO DEVIATE SURFACE WATER

e = BERM 10' TO 20' WIDE

Fig. 5.

Some of these artificial ponds are even larger than stated above; that of Temavasio, for example, is 20 hectares (49 acres) in area and has a water depth of 5 metres (16 feet), sufficient to irrigate—very sparingly, but sufficiently—during 6 to 7 months about 50 hectares (123 acres) of meadows.

The capital cost of these ponds per cubic metre of water stored is about francs 0.20 to 0.25 (from 18 cents to 25 cents per 1000 gallons), including all expenses; and the cost of the water, including interest and all other expenses and also distribution over the land, comes to about francs 0.012 to 0.016 per cubic metre (one to one and a half cents per 1000 gallons).

This price is, however, still too high for irrigation on a large scale; and besides, the quantity of water thus stored is, comparatively, very small. As the water has to be used with great economy, the grass during the hottest months suffers somewhat from drought.

(e) Storage of Water in Large Artificial Lakes. Large reservoirs, or artificial lakes, of many million cubic metres capacity have been formed in several valleys of the Alps or of

Fig. 6. Small Reservoir at Lische. View When Nearly Empty.

the Apennines by high dams of earth, rock-fill or masonry, the latter being generally used.

In fact, except for the small reservoirs, or "tanks", just described, earth dams are not popular in Italy, and are rarely built higher than 30 to 40 feet. The only high earth dam is at Lagastrello, in the province of Parma. It is 21 metres high (69 feet), 170 metres (550 feet) long on the crest, and forms a reservoir of 3 million cubic metres (657 million gallons), or 2400 acre-feet, capacity. (Fig. 7.) As a rule, owing to the peculiar

climatic condition of its watershed, this reservoir is filled about three or four times a year by the exceptional rains of the region; so really it acts as if its volume were from 9 to 12 million cubic metres, and thus the unit cost of the impounding capacity of the reservoir is much smaller. Its total cost was 620,000 francs ($124,000), and the cost per cubic metre of water impounded comes to about 0.02 francs (18 cents per 1000 gallons). The water is drawn at the rate of 1 cubic metre per second, being utilized, first, for an hydro-electric installation of about 10,000 hp., and afterwards for irrigation.

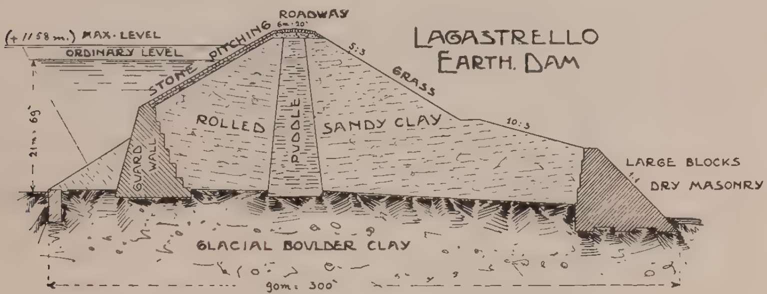


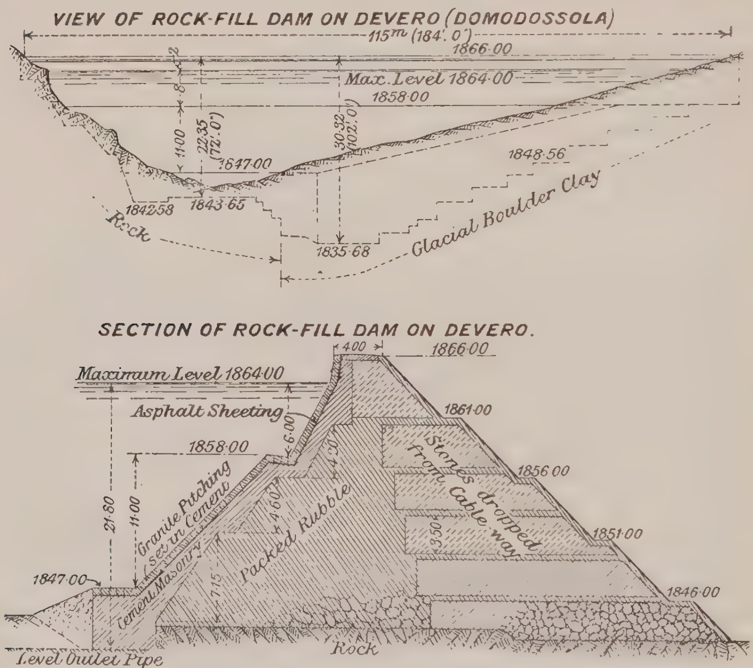
Fig. 7. The Only High Earth Dam in Italy.

It may be well here to add that all of the water from the large reservoirs of Italy serves, first, for hydro-electric power, and afterwards, for irrigation; otherwise, it would not be possible to pay the interest on the capital invested; and even then the State has to encourage these enterprises by granting a subsidy that, in some cases, reaches 3% per year during the first 10 years and 2% and 1% per year during the following decades. This, capitalized at the rate of 5% interest, makes an initial grant of 35% on the capital invested. The grant, however, is given on condition that the water for irrigation will not cost the farmer more than 0.01 francs per cubic metre (0.9 cents per 1000 gallons)—generally it is sold at much less; otherwise, the farmers could not afford the expense.

Just now, Parliament is considering the advisability of increasing this subsidy to 3000 francs ($600) per annum, for 50 years, for each million cubic metres (35 million cubic feet) of

water capacity of the lake. At the end of 60 years, the reservoir and distributing canals become the property of the State.

The other type of dam which is coming into favour in Italy—because of its low cost and resistance even to earthquakes, which are not infrequent in Southern Italy—is the rock-fill dam.* There are, already, three good examples of these rock-fill dams that have been built recently: at Lago D'Alpone (Mont-



Figs. 8 and 9. Important Example of Rock-fill Dam in Italy.

cenis), at Biaschina (Tessin) and at Devero (Domodossola). (Figs. 8 and 9.) The latter, which is the most important, is 31 m. (101 feet) high, 115 m. long (365 feet) on the crest and is formed by a mass of large stones roughly packed with smaller ones. It is protected on the water slope by a layer of first-class cement masonry, made still more impermeable by a double layer of asphalt-sheeting, which, in turn, is protected by a granite

* Luiggi, "Le dighe di scogliera (Rock-fill Dams) per le regioni sismiche", Roma, 1914.

pitching set in mortar. The volume of the reservoir is 13 million cubic metres (11,000 acre-feet), and its cost was 868,000 francs ($143,000) or 0.07 francs per cubic metre (6.5 cents per 1000 gallons) storage capacity.

The Brasimone dam (Fig. 10), in the Province of Bologna, is one of the best types of Italian masonry dams; and the Tirso, Bradano and Fortore dams are planned on the same lines. It is 34 metres (112 feet) high, 158 metres (530 feet) long on the crest and has a volume of 40,000 cubic metres (about 50,000 cu. yds.) of masonry. It is calculated as a gravity dam, but for

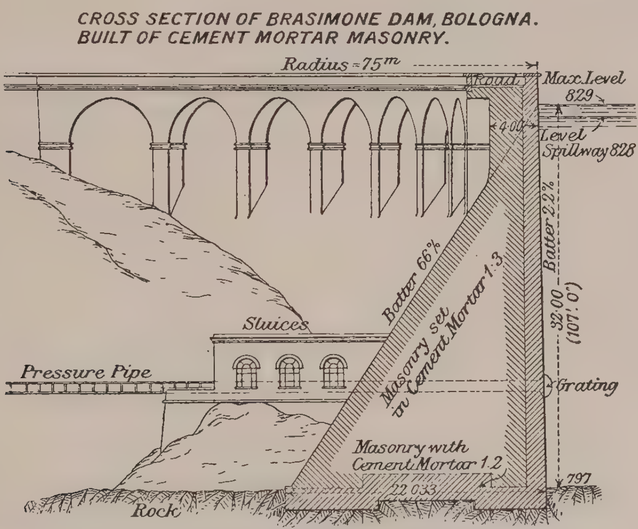


Fig. 10. Best Type of Masonry Dam in Italy.

greater safety it is arched in plan, with a radius of 75 metres (250 feet) and subtending an angle at the centre of 126°. Its section is considered quite up to date, combining the maximum of safety with proper economy; its cost was 800,000 francs ($130,000), with accessories. The volume of the reservoir being 5,600,000 cubic metres (4580 acre-feet), the cost is francs 0.14 per cubic metre (12 cents per 1000 gallons) storage capacity of the reservoir.

Another interesting dam, very daring in design, and with a cross-section very similar to the Bear Valley dam in California

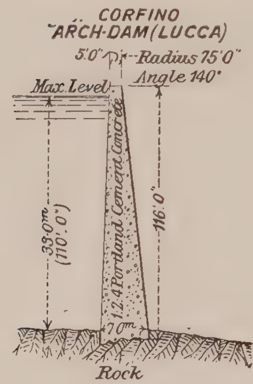


Fig. 11. Corfino Arch Dam. Built in 65 Days.

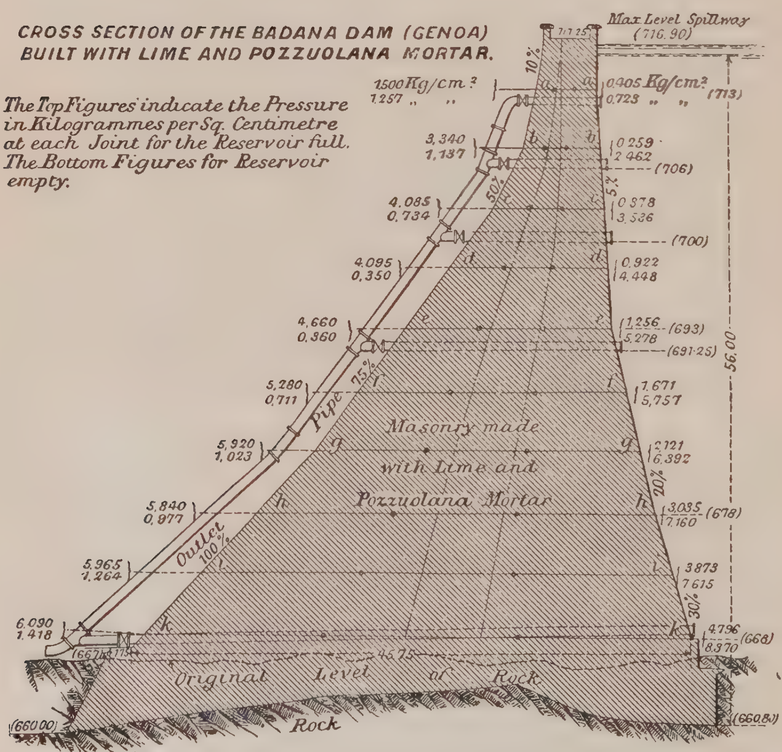


Fig. 12. The "Badana Dam", the Highest in Italy.

or to the concrete dams built by Mr. Wade in Australia, is that of Corfino, in the province of Lucca. It is not a gravity dam, but an arched dam 35 metres (116 ft.) high, with a radius of 23 metres (75 ft.) and a central angle of 140 degrees. (Fig. 11.) Its thickness on the crest is only 1.50 metres (5 ft.), and at the base is 7 metres (23 ft.). It was built in 65 days, by pouring Portland-cement concrete, 1:2:4 mixed rather wet, into the wooden moulds. It gave very good results, both technically and

Fig. 12a. Automatic Syphon Spillway of the Badana Dam. 3150 Sec.-Ft. Discharge. Spillway at Right.

financially, and its cost was only 150,000 francs ($30,000): its capacity being 800,000 cubic metres, the unit cost is francs 0.25 per cubic metre (12 cents per 1000 gallons) of storage capacity.

However, the most important group of dams, five in all, just finished on the River Gorzente, near Genova, include the Badana dam (Figs. 12 and 12a), 56 metres (188 feet) high—at present, the highest in Italy. It is 215 metres (715 feet) long on the crest, has a volume of masonry of 100,000 cubic metres (132,000 cubic yards) and its cost was 2,325,000 francs ($465,000). It forms a

lake of 450,000 cubic metres capacity (354 acre-feet); thus the unit cost of the water impounded is francs 0.49 per cu. m. (45 cents per 1000 gallons).

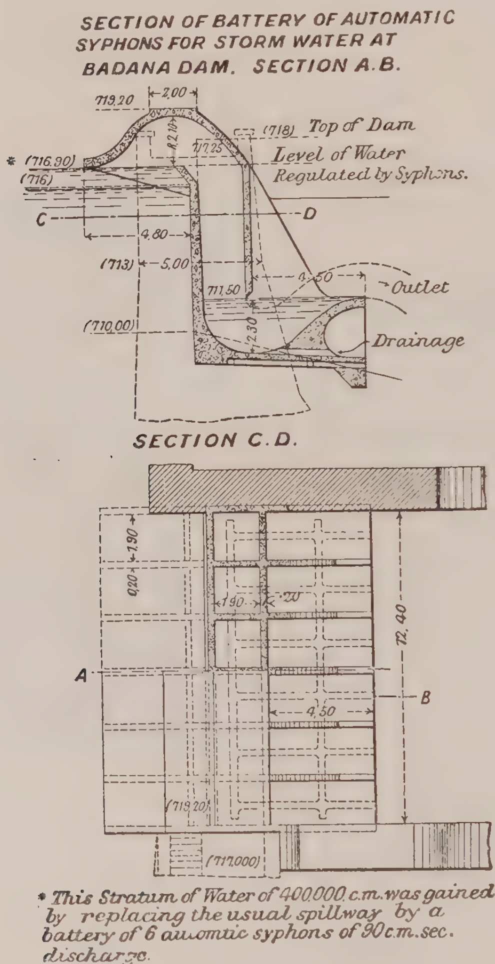


Fig. 13. Automatic Syphon Spillway.

A special feature of the dams of this group is that the flood-water is not discharged over the usual overflow spillways, but by means of a series of automatic syphons (Figs. 12 and 13). In the Badana dam there are six syphons, with a total discharge of

90 cubic metres per second (3150 sec-feet). In the Lagolungo dam there are ten syphons, with a total discharge of 150 cubic metres per sec. (5250 sec-feet).

This is, perhaps, the largest group of automatic syphons existing, and they have given excellent results for several years.* Many others are in use on the different irrigation canals, and on the Cavour Canal there are several examples. As already mentioned, on the River Tirso, Sardinia, there is now in construction one of the most important reservoirs, having in view the triple object of (a) regulating the floods of this torrential river, which has a maximum discharge of nearly 1300 cubic metres (45,500 sec-ft.) of water; (b) of using the impounded water for a 12,000-hp. electric installation; and (c) of using its 20 cubic metres per sec. (750 sec-ft.) discharge, during summer, for the irrigation of about 30,000 hectares (74,000 acres) of the plains around Oristano.

The dam is 55 metres (195 feet) high (Fig. 14), and will impound, as already said, 350 million cubic metres (285,000 acre-feet) of water, at a cost, including electric plant and irrigation canals, of 25 million francs ($5,000,000). The State contributes a sum of 3 million francs ($600,000), and also 150,000 francs ($30,000) per year during 50 years, on condition that the price of the irrigation water will not be more than 0.005 francs per cubic metre (0.5 cent per 1000 gallons). At the lapse of 60 years, all the works become the property of the State.

As already stated, the water from all these artificial lakes is always used first for motive power in some of the hydro-electric installations, which, in Northern Italy, are very numerous. This helps greatly in lowering the price of irrigation water, which, afterwards, can be distributed by means of canals to the different farms at prices varying from about 0.005 to 0.01 francs per cubic metre (from ½ cent to 1 cent per 1000 gallons), or at an ''annual rate'' of from 80 to 120 francs per hectare of land ($12.50 to $17.50 per acre per annum).

(f) **Water Derived from Rivers.** These prices are quite acceptable in semi-arid regions, such as Apulia, Calabria, Sicily and Sardinia, where three or four irrigations during the period from

* Luiggi, ''Dighe recentemente costrutte in Italia'', Roma, Giornale Genio Civile, 1914.

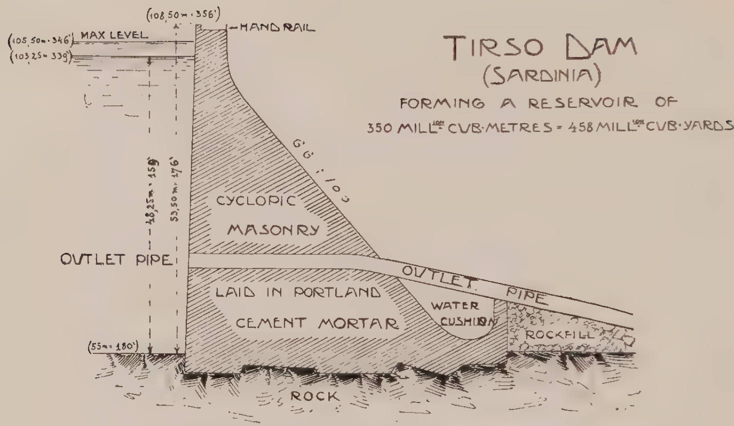


Fig. 14. High Masonry Dam under Construction in Sardinia.

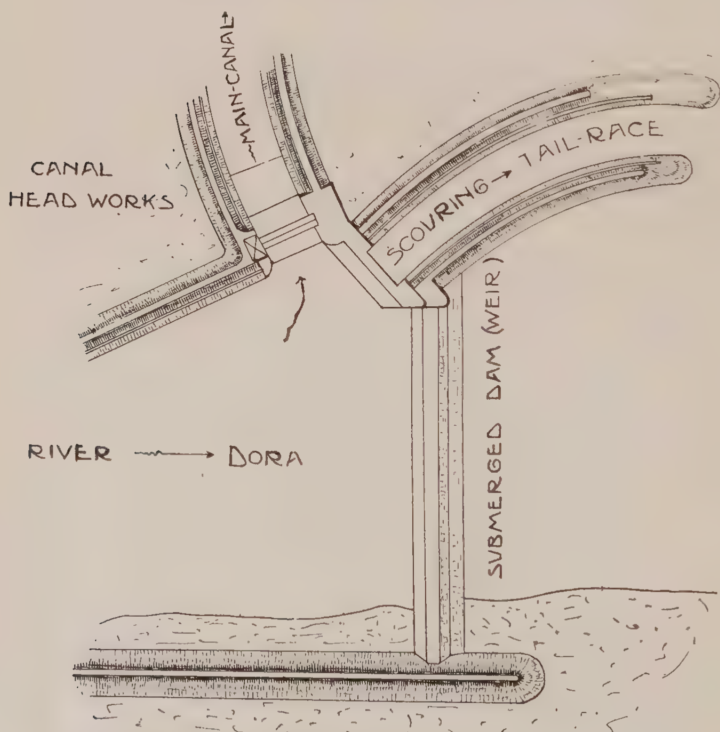


Fig. 15. Headworks of the Cavour Canal (Farini Branch).

March 15 to May 15, when the plants are in full growth, may even save the crops from total failure and fully repay the expenditure on the water. Besides, they may allow of another and later crop, such as maize, potatoes, melons, etc., to be raised. However, they are still too high for ordinary irrigations, especially of meadows, which form the most important feature of the plains of Lombardy and Piedmont. Besides, for very large areas of land, the quantity of water that can be impounded in an artificial lake is always comparatively small. The discharge from these lakes may vary from a few cubic metres to 20 cubic metres per second (750 sec-feet), as in the Tirso district, or even

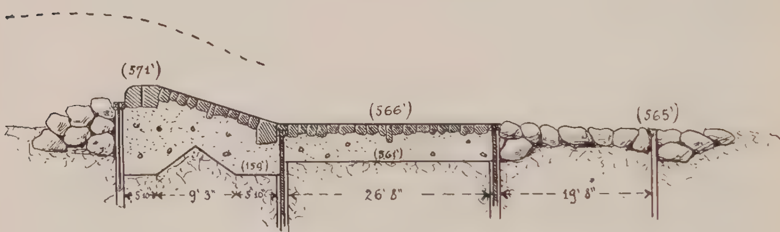
Fig. 16. Headworks for 70 Cu. M. per Sec. Discharge on Farini Branch of Cavour Canal. Regulating Sluice at Left; Scouring Sluice at Right.

to 44 cubic metres per second (1540 sec-feet), as in the Fortore valley. But these specific cases mentioned are quite exceptional.

So, when larger quantities are required, and at a very low price, then it is necessary to obtain the water from rivers, fed either by some natural lake—as are the Rivers Ticino, Adda, Oglio and Mincio, whose waters are comparatively warm—or by glaciers, which, melting in the summer, act practically like lakes of frozen water; in this latter class are the Rivers Tanaro, Po (down to Turin), Dora, Sesia, Orco, Adige and many others. These waters, however, are rather cold and are not so efficient as the waters from reservoirs or lakes.

In the case of diversion from a river, the engineering works,

called *derivazioni*, consist (Fig. 15), in general: (a) of a weir or submerged dam, of very substantial masonry, built across the river and capable of raising the level of the water above that of the country to be irrigated (Figs. 17, 18, 19, 20, 21, 22 and 23); (b) of some controlling sluices at the canal head (*edificio di presa*) (Fig. 16), which may be as many as twenty, as for instance in the Villoresi Canal (Figs. 21 and 22); (c) of another group of sluices (*disarenatore*) adjacent to the controlling sluices, arranged in such a way as to cause a strong current across the entrance of the canal (Figs. 15 and 16) and thus scour away the solid matter that has a tendency to deposit in front of the main sluices and then creep into the canal. Then follows the main canal, with a fall from 0.15 m. (6 inches) to 0.50 m. (1 ft. 8



CROSS SECTION. OF WEIR

Fig. 17. Submerged Dam at Farini Branch of Cavour Canal.

inches) in 1000 metres (3280 feet), according to the section of the canal and the volume of water, in order to keep the velocity of the water at least as great as 0.50 m. (1.67 ft.) per second, so as to prevent silting, and not to exceed 0.70 m. (2 ft. 8 inches) per second in ordinary cuttings, so as not to erode the banks. Otherwise, they must be heavily protected by a revetment. In aqueducts, inverted syphons, and such constructions of masonry, the velocity is kept between 1.2 metres (4 ft.) and 2 metres (6. 5 ft.), and in exceptional cases, even 3 metres (10 ft.) per second—but then the masonry must be laid in cement-mortar.

The main canal is provided with the usual controlling works, such as overflows, scouring outlets and regulating weirs, at the entrances to the secondary canals (Fig. 27). These latter canals have a fall of from 1 to 2 metres per 1000 metres and feed the

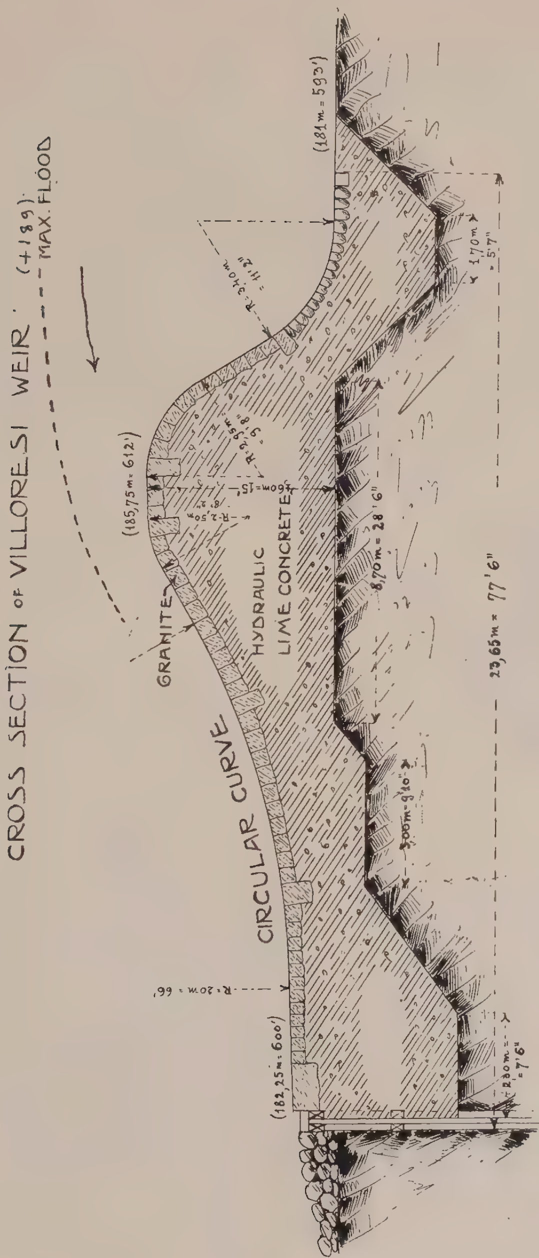


Fig. 18. Villoresi Weir, River Ticino, Lombardy.

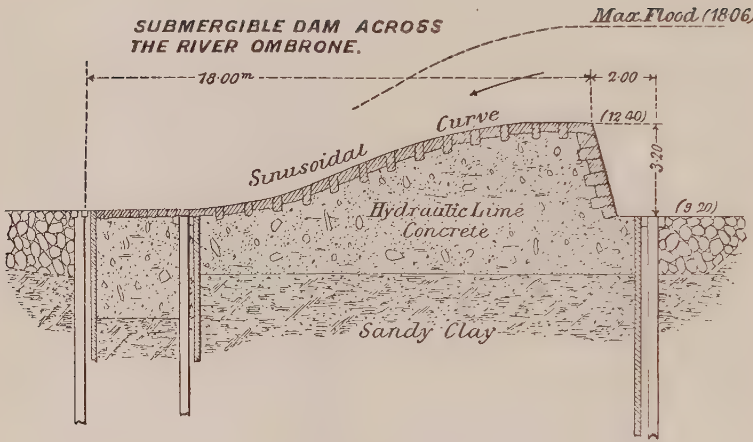


Fig. 19. Weir Across River Ombrone.

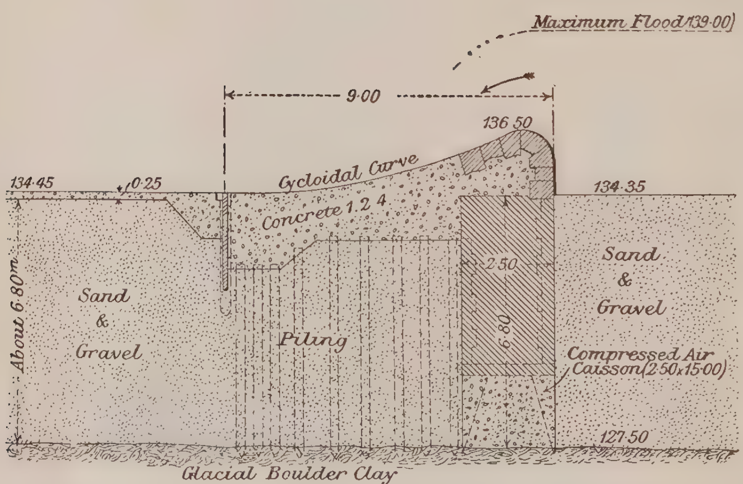


Fig. 20. Weir Across River Cervo, a Feeder of the Cavour Canal.

private or distributing ditches, which are provided at their intakes with some means for measuring the water to be delivered. Generally a submerged orifice or a "Cipolletti weir" (Fig. 30), or some such overfall "notch", is used, provided it is accurate within 2% of the true discharge.

No mechanical meters are adopted, except in very rare cases and for very small deliveries.

Many of these irrigation canals date back to the Middle Ages and are used also for inland navigation—in fact, this is a feature of the Italian canals called *navigli,* i. e., to serve both

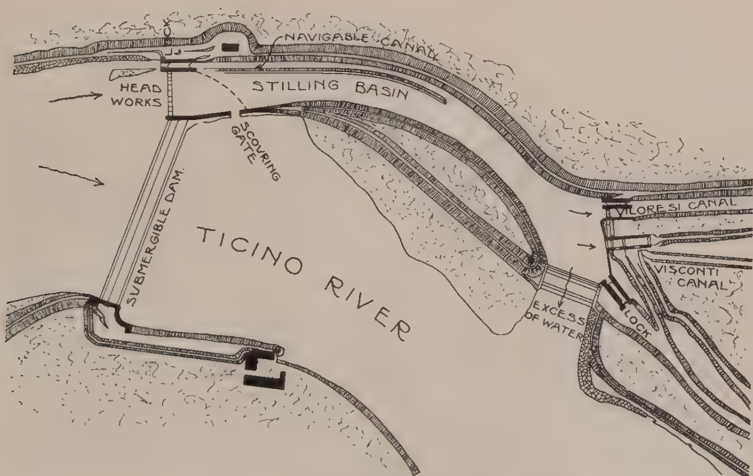


Fig. 21. Headworks of Villoresi Canal.

for irrigation and navigation purposes. It was on these *navigli* that Leonardo da Vinci built the first locks to allow boats to pass from one reach of a canal to another at a lower or a higher level.

The oldest is the "Naviglio Grande" of Milan, built in the 12th century; it is about 50 miles long and has a discharge capacity of 65 cubic metres per second (2275 sec-ft.). Next in order of date comes the "Muzza" from the "Adda", with 60 cubic metres per second (2100 sec-ft.); then the "Naviglio" of Cremona, from the Oglio, with 30 cubic metres per second (1050 sec-ft.), and many others, all about 5 to 6 centuries old; and

several hundreds of smaller canals, discharging from 5 to 20 cubic metres per second.

The canals of modern times, that is, those built during the last 50 years—since Italy was united in one State—merit special attention. The largest and longest of all is the Cavour Canal, with a discharge capacity of 110 cu.m.sec. (3850 sec-feet), a development of about 70 miles of main canals and about 950 miles of secondary canals and distributing ditches; that is, a total of over 1000 miles. It was begun in 1855 by a private company that failed, and was bought over and finished, in 1866,

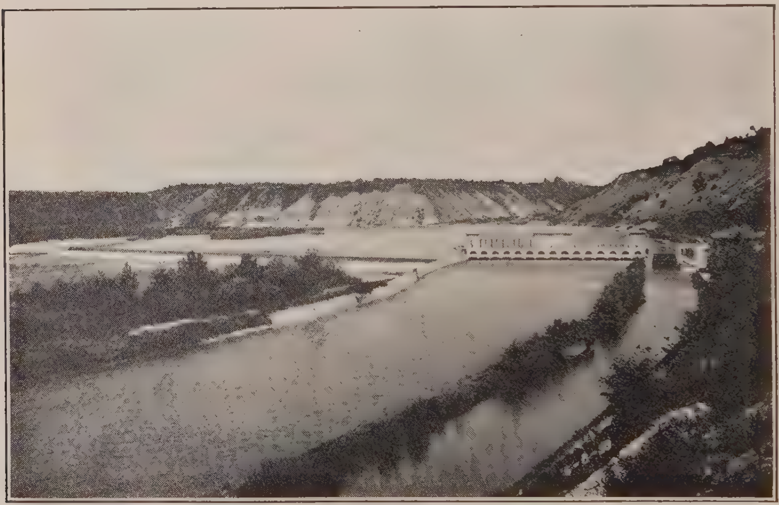


Fig. 22. Headworks of the Villoresi Canal, Ticino River, near Milan. Villoresi Canal in Center; Navigable Canal on Right.

by the State at a cost of about 100 million francs ($20,000,000). This canal—still the most important in Europe—was the means of transforming the almost barren region of Piedmont, of 250,000 acres of gravelly lands—growing only stunted timber and bushes, and giving a gross revenue of 20 to 25 francs per hectare ($4 to $5 per acre) per year—into the most fertile rice fields and meadow-lands of Italy, where the best butter and parmesan and gorgonzola cheeses are produced, and where rents now vary from 200 to 300 francs per hectare ($40 to $60 per acre).

Then, in degrees of importance, and also from the point of

view of their engineering features, follow the Villoresi Canal (Figs. 21 and 22), with a discharge of 44 cubic metres per second (1450 sec-feet); the Marzano Canal, with 30 cubic metres per second (1050 sec-feet); the Veronese Canal, with 15 cubic metres per second (525 sec-feet); and the Tagliamento Canal, with 17.5 cubic metres per second (617 sec-feet). They are all excellent models of their kind, both for the important hydraulic works along their courses and the perfection of their administration; so much so, that hydraulic engineers and agriculturists from all parts of the world come to visit and study them.

Another large canal, called the "Emiliano", from Piacenza to Bologna and Rimini, is in project. It will be 300 kilometres

Fig. 23. Ombrone Canal Headworks for 21,000 Cu. Ft. per Sec. Perhaps the Largest in the World.

long, with 200 cubic metres per second (7000 sec-feet) capacity, and will cost about 250 million francs ($50,000,000).

And a still larger canal is now in course of construction, near Grosseto, in Central Italy, of 600 cubic metres per second (21,000 sec-ft.) capacity, which will be in working order in 1915*. It will utilize the muddy waters of the River Ombrone (Figs. 23 and 23a)—which, in flood, carry as much as 10% of solid matter—in order to silt up some large marshes and transform them into excellent arable land, as has been done on a large scale and with very good results, both from a sanitary and agricultural point of view, around Ravenna, Grosseto, Caserta and

* Luiggi, "La derivazione dell' Ombrone di 600 c.m. per secondo", Giornale Genio Civile, Roma, 1914.

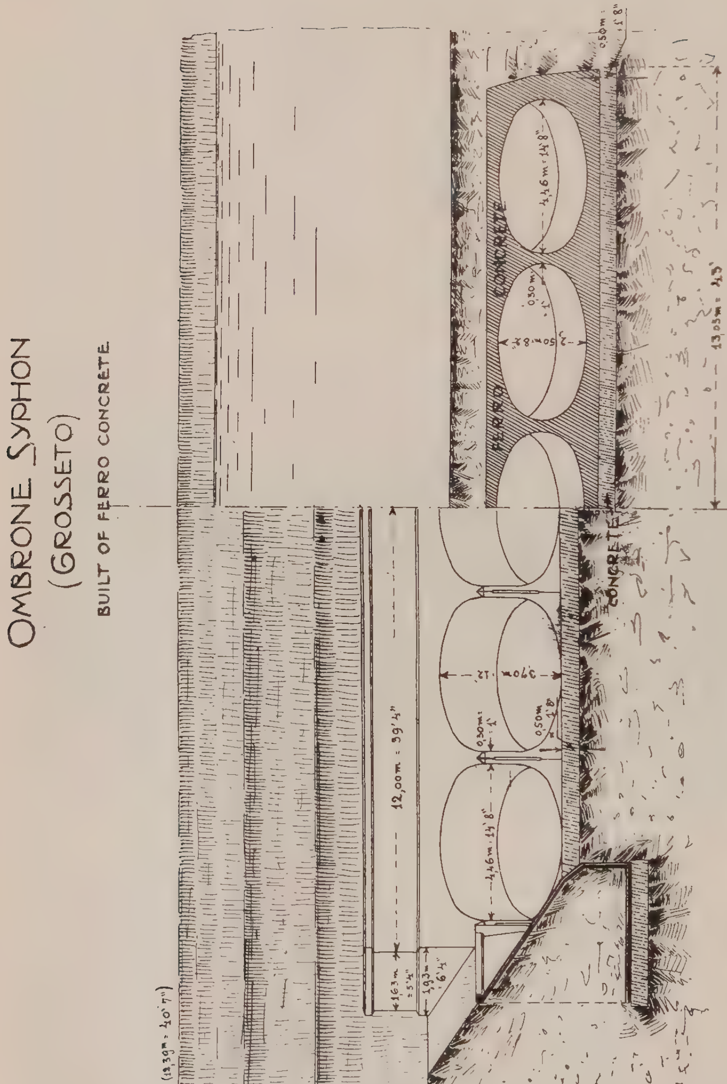


Fig. 23a. Reinforced Concrete Syphon under the River Ombrone. Discharge of 21,000 Sec-Ft.

other provinces. When the level of the land, by this process of gradual silting up, has been raised some 2 or 3 feet above the natural water-plane of the district—or when the *colmata,* as it is called, is complete—then the headworks and the canal will be slightly altered; that is, the sill will be raised in order to prevent too much silt coming in, and the canal will then be used for both irrigation and navigation.

This will probably be one of the largest canals in the world, as those derived from the Ganges and the Euphrates carry only about one third and three fifths as much water, respectively, as the Ombrone Canal, and will be surpassed only by the Ibrahimieh Canal, derived from the Nile, with about 900 cubic metres per second (31,500 sec-feet) capacity.

(g) **Cost of the Water.** The water from the State canals is charged for, generally, at the rate of 25 francs ($5) per litre per second per year, which corresponds to a volume of about 30,000 cubic metres (1,050,000 cu. ft., or 10 acre-feet) per annum, discounting the time when the canals are dry for ordinary repairs. Thus, the cost of the water comes to about 0.83 francs per 1000 cubic metres. This "one litre second" is the normal quantity of water that, in Northern Italy, is considered necessary for the irrigation of one hectare of land; measured at the intake of the canal, it means a uniform depth of water of 10 feet applied to the land during the 12 months. It also means an expenditure of about $1.60 per acre per year. As, however, the irrigation is necessary only during the 5 to 7 months of the dry season, only one half of this amount, or about 15,000 to 20,000 cubic metres, of water is really used; the rest is lost. Thus the cost of the water is actually from 1.02 francs to 1.66 francs per 1000 cubic metres ($1.00 to $1.50 per million gallons); that is, on the average, only one fifth of what it would cost if taken from the Tirso reservoir, which is the cheapest reservoir water in Italy; or from one tenth to one twentieth that of the water taken from ordinary tanks (*bacini a corona*) or artificial lakes or underground supplies (*gallerie filtranti* and *fontanili*).

When water can be had at such low rates from the State canals, or even at double this price, either from the Villoresi, Marzano and other great canals belonging to private corporations, then irrigation amply repays all its cost, even for com-

paratively poor crops, like grass; and pays better still for richer crops, like rice, Indian corn, tomatoes, melons, etc. Then farming becomes very profitable, and this explains the comparative wealth of the farmers of Northern Italy, who have practised irrigation from very ancient times and are still extending it steadily to new districts.

(h) **Engineering Features of Canals.** It would be too long and tedious to describe, even rapidly, the very interesting and important engineering features of these canals, especially of the Villoresi and Marzano Canals, which, being the latest, are the most perfect. It would certainly be most interesting for engineers to examine their majestic headworks, the inverted

Fig. 24. Aqueduct over River Dora on Cavour Canal. Discharge, 110 Cu. M. per Sec. (3850 Sec-Ft.)

syphons and aqueducts that convey the water under or over the different streams and roads crossed by the canal, and all the smaller, but ingenious, artifices for the delivery and the best use of the water.

It will be sufficient to give the plans of some of the most typical works; for example, the headworks of the Farini Canal, a feeder of the Cavour Canal of 70 cubic metres per second (2250 sec-feet) capacity (Fig. 16); the inverted syphon of masonry under the River Sesia (Figs. 25 and 26) which discharges 110 cubic metres per second; the aqueduct over the River Dora (Fig. 24); the inverted syphon of ferro-concrete, of 600 cubic metres per second (21,000 sec-feet) capacity, under

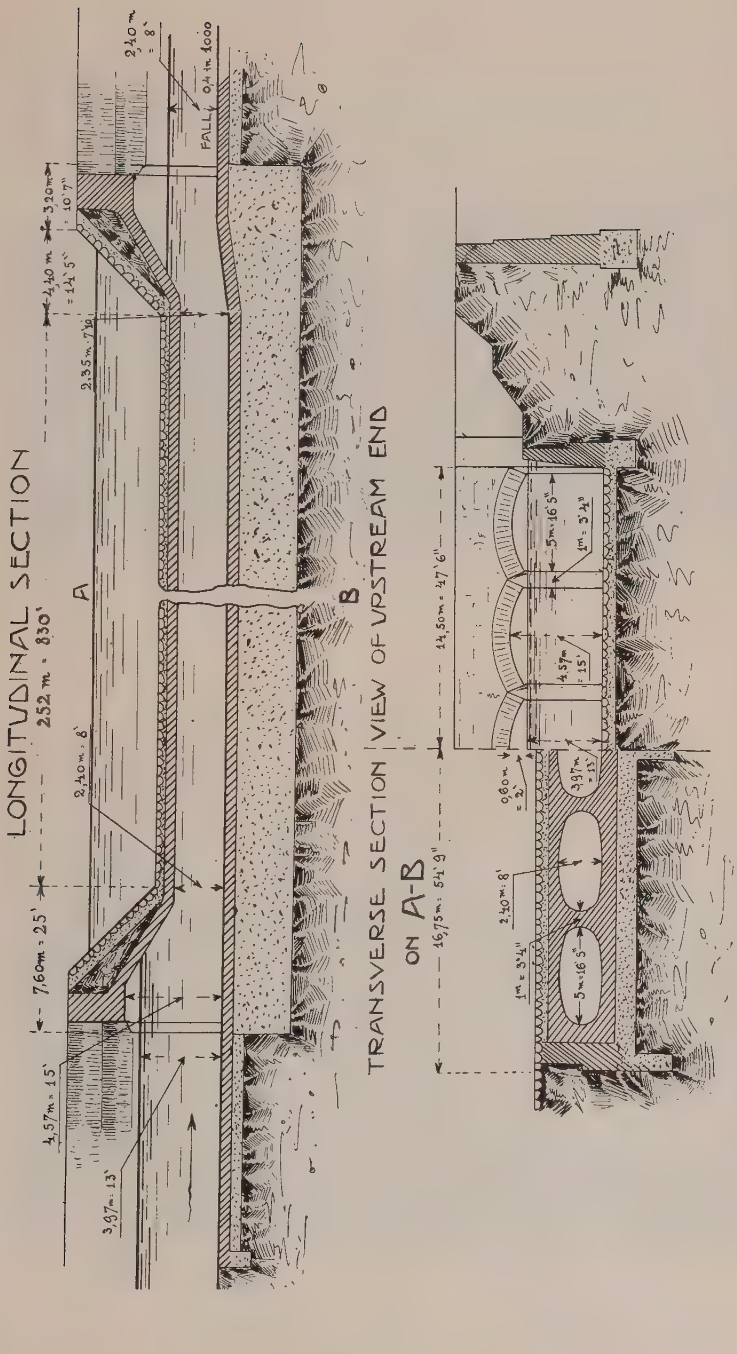


Fig. 25. Syphon under River Sesia, Cavour Canal.

Fig. 26. Syphon under River Sesia on Cavour Canal. 3850 Sec-Ft. Discharge.

Fig. 27. Marzano Canal and Take-off of Naviglio, on the Right.

the Ombrone (Fig. 23a); the aqueduct and syphon of the Marzano Canal, over some other canals, of 30 cubic metres per second capacity, etc.

All these works can be easily inspected during a journey of two weeks between Turin, Milan, Cremona, Mantova and Venice, and will amply repay any one interested in irrigation. Thus he will be able not only to see the engineering features of the canals, but to ascertain their beneficial effects. The land in those provinces was transformed, almost created, from barren, sandy and gravel plains into the most fertile vegetable soil by

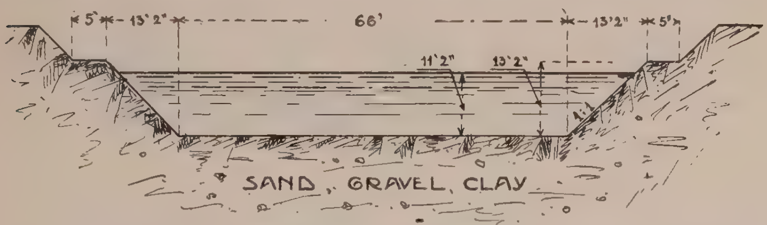


Fig. 28. Cavour Canal, Section in Earth Gradient, 1 in 4000; Discharge, 3850 Sec.-Ft.

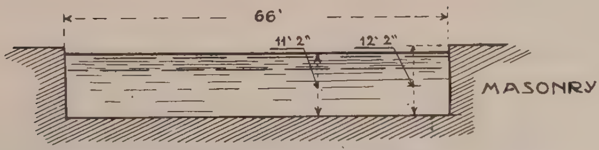


Fig. 28a. Aqueduct over River Dora on Cavour Canal. Gradient, 1 in 2500; Discharge, 3850 Sec-Ft.

the silt gradually deposited by the irrigation water. Where, about 50 years ago, there was very poor agriculture and a miserable population, farming is now carried on with great success, and the country people enjoy a comparative comfort and are content, at least, as far as farmers can be.

They only clamour for more irrigation water and complain when it rains out of season; because, contrary to the ordinary conditions of agriculture, when irrigation is adopted, the best crops are produced when there is constant sunshine—as in Egypt, where it never rains.

The Western States of America then offer ideal conditions for successful irrigation.

HOW THE WATER IS APPLIED AND THE RESULTS OBTAINED.

Preparation of the Land to be Irrigated. However, to apply irrigation with a certainty of success and to get from the water and the soil the maximum benefit, it is necessary to prepare the surface of the land; that is, it must be properly leveled, or better still, given a slight inclination from the irrigating ditches towards the drainage ditch, in order to prevent water-logging; then, all the ditches have to be prepared and the intercepting sluices put in place.

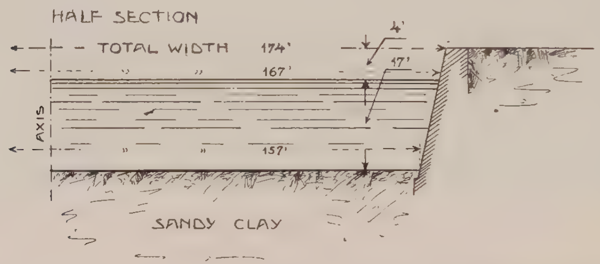


Fig. 29. Section of Ombrone Canal with Side Walls. Discharge, 21,000 Sec.-Ft.

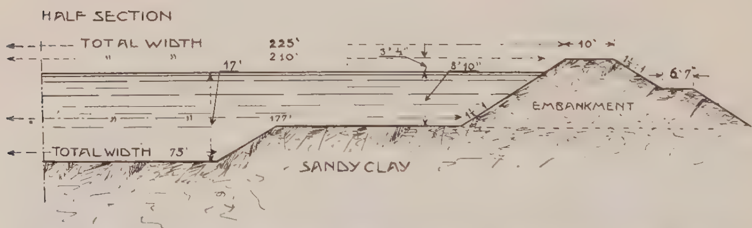


Fig. 29a. Section of Ombrone Canal in Earth. Discharge, 21,000 Sec-Ft.

All this, under most favorable conditions, costs 200 to 300 francs per hectare ($40 to $60 per acre); but where the natural ground is rather irregular, as much as 600 to 700 francs per hectare ($115 to $135 per acre) may be required.

In some cases, where the surface falls towards the north, it is even convenient to give it a slope towards the south, with an inclination of from 3° to 5°, in order to get the full benefit of the sunshine. For this purpose, the top layer of vegetable soil is stripped off and laid by, the subsoil arranged with the

proper grandients, and then the top layer is redeposited on the surface. When a *marcita*, or a super-irrigated meadow, is to be prepared, then the whole field is arranged in plots (Fig. 31) about 6 metres (20 ft.) wide and 60 to 90 metres (200 to 300 ft.) long, with a lateral fall of 0.15 m. (6 in.) and sloping alternately almost like some flat roofs laid all along side of each other. On the top of the ridge between two adjacent plots runs the irrigating ditch; the water, overflowing from this ditch, runs slowly

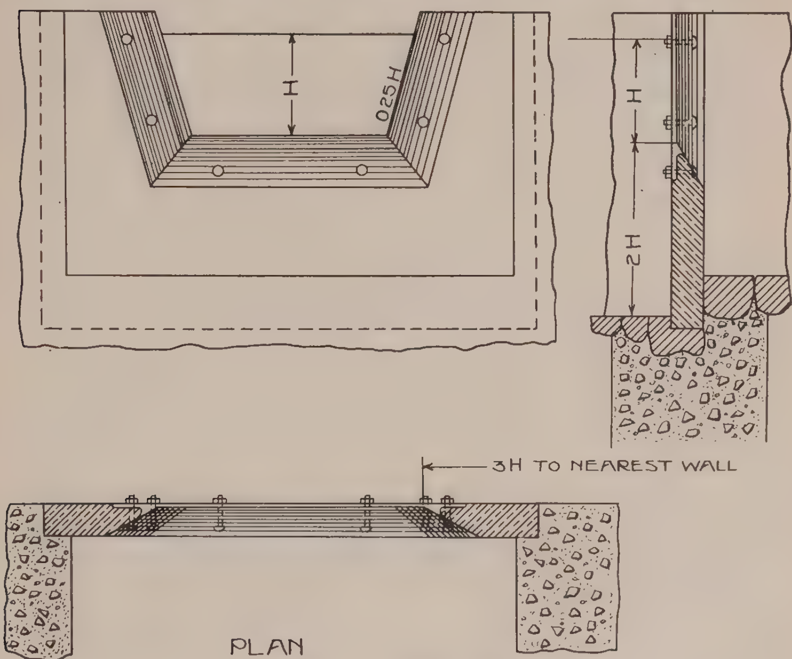


Fig. 30. Cipoletti Weir.

down the slope of each plot, and the surplus is collected by the draining ditch. Each plot being slightly higher than the one next below, the run-off water from the drainage ditch can flow along to the next irrigating ditch and overflow on to the next two sloping plots; in this way, all the water is fully utilized.

All this requires work and capital. In Northern Italy, where irrigation has been in practice from time immemorial on a very large scale, the capital is easily obtained and paid off in

some 30 to 50 years; but in the South, where irrigation is still in its infancy and capital is very scarce, the State comes to the aid of the farmer by lending the money at 2 to 2½%, to be repaid in 50 to 40 years. The farmer, with the advice of some Government official appointed for this object, prepares and presents a plan of what he intends to do; this plan has to be approved; then the State lends out the capital in installments as the work advances; and at the same time, a mortgage is put on the land.

This arrangement works pretty well, especially in the Compagna Romana, which is being rapidly transformed—from an almost waste land, very thinly populated by poor, nomadic peasants—into good corn land and meadow land, with proper farm buildings and a settled population. At present, some parts

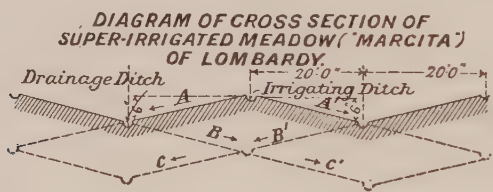


Fig. 31.

of it can compare with the best districts of Lombardy, thanks to the land being more fertile, owing to its volcanic origin, and to a larger amount of sunshine during the year.

Thus, irrigation begins to have a beneficial social influence around Rome, in a region of about 450,000 acres that was considered almost beyond redemption and where malarial fever reigned supreme.

Thanks to irrigation and cultivation on a proper scale, malaria is abating rapidly, and Rome will soon be surrounded again by beautiful fields, as it was in olden times, when 64 large villages, some with most luxurious villas, were flourishing in that region. Today, we find remains of these villages when the plough cuts again the long-abandoned soil.

Quantity of Water Required, and Economical Results Obtained from Irrigation. It would be very interesting, but beyond the scope of this paper, to mention the ingenuity dis-

played in using the water to the best advantage in order to increase the production of special crops, such as oranges, fruit, early vegetables, and flowers for distilling purposes; accordingly, only the production of the most usual crops, such as grass and cereals—the staple branches of Italian agriculture—will be considered; also, because they are the only ones that might interest American farmers.

Where the land can be super-irrigated, as in the *marcite,* and the water is raised from underground—and thus has an almost constant temperature of 55° to 60° F.—irrigation can be practised even during the winter months; then some 20,000 to 25,000 cubic metres of water are required per hectare, at a cost of 25 to 50 francs per hectare ($2 to $4 per acre). The water is applied in ''rotation'' every 8 to 15 days at the rate of 800 to 1000 cubic metres per hectare, corresponding to a depth of water of from 8 to 10 centimetres (about 3 to 4 in.) at each rotation.

The *marcite* can produce 7 to 8 cuttings of lucerne or trefoil grass per year, at the rate of at least 500 to 600 quintals per hectare (400 to 500 cwt. per acre) and in the best *marcite,* even 800 to 1000 quintals (640 to 800 cwt. per acre)—sufficient to feed two cows per hectare, which produce 26 to 30 quintals of milk* (10.4 to 12 cwt. per acre). This milk is sold, at 13 to 16 francs a quintal, for dairy purposes and gives a gross revenue of about 350 to 400 francs per hectare ($30 to $35 per acre), against an expenditure of 100 to 120 francs per hectare ($8 to $10 per acre) for water and labour, leaving a very good profit to the farmer.

In the ordinary irrigated meadows, where water is applied at the rate of 15,000 cubic metres per hectare (corresponding to a depth of 5 feet) during the 5 to 7 warm months, the profit is smaller, as there are only 5 to 6 cuttings, with a total weight of grass from 400 to 500 quintals per hectare (160 to 200 cwt. per acre). A good meadow not irrigated is rented at 150 to 200 francs per hectare ($14 to $18 per acre); but when it can be irrigated, its rent is raised to, at least, 250 to 300 francs per hectare ($25 to $28 per acre), or almost double,

* On large farms, milk is always sold by weight; it is easier and there is less danger of contamination. One quintal is equal to 2 cwt.

whilst the expenditure is not much more than in the case of the unirrigated land.

In the Roman Compagna, where the land is less permeable than in Lombardy, the water necessary during the dry season for irrigated meadows varies from 7000 to 9000 cubic metres per hectare (245,000 to 350,000 cu. ft. per acre, or about 2½ to 3 acre-feet), and is applied at the rate of 500 to 600 cubic metres per hectare (17,500 to 21,000 cu. ft.) every 10 to 12 days. The rent paid by the farmer for unirrigated land near Rome varies from 100 to 150 francs per hectare ($9 to $13 per acre), but when irrigated, the rent is just double, and sometimes more. The most profitable crop cultivated is grass for feeding stock, as Rome consumes a large amount of milk, which can be sold by the farmer at 22 to 24 francs per quintal ($4.50 to $5 per 21½ gallons—1 quintal—or about 20 to 21 cents per gallon). Thus, meadow-land produces a very good rent and irrigation is being extended rapidly in the district around Rome.

In the Southern Provinces, especially in Apulia, where, owing to the peculiarities of the rainfall, cereals are cultivated on a large scale in preference to grass, the usual production, in ordinary years, is 8 to 10 quintals of wheat per hectare (6½ cwt. per acre). In very good years, when the rainfall amounts to 180 to 200 mm. (7 to 8 in.) during the period in which the plants are in full growth—that is, between March 15 and May 15—then 16 to 18 quintals (13 to 16 cwt. per acre) of wheat per hectare are produced; but in dry years, the product is only 4 to 5 quintals per hectare (2 to 3 cwt. per acre), and in poor soil, the crops may be entirely lost.

With irrigation, even at the very low rate of 2000 to 2500 cubic metres of water per hectare (28,000 to 35,000 cubic feet per acre; less than 1 acre-foot), applied in 4 rotations during the two months mentioned, when the wheat is in full development, a production of 16 to 18 quintals of wheat per hectare is assured every year, instead of the usual average of 8 to 10 quintals per hectare on land not irrigated. Thus, even paying for the water at the very high price of 0.03 to 0.04 francs per cubic metre (2½ to 3 cents per 1000 gallons—as it costs in Apulia, where water is scarce—with an expenditure of 80 to

100 francs per hectare ($7.50 to $10 per acre), a larger crop, valued at about 140 to 180 francs, is assured, leaving an average net profit of 70 francs per hectare (about $7 per acre); so irrigation not only repays amply for the water used and guarantees always a good crop, but leaves also a fair surplus. It acts in reality as an insurance against all climatic risks.

After the cereals have been gathered, some other plants of rapid growth, like tomatoes, watermelons, cabbages, etc., are planted and well irrigated; and thus, thanks to the abundance of sunshine, a second crop can be gathered in one year.

This explains why the farmers of Apulia, Sicily and Sardinia clamour for irrigation; for they know by experience that water applied at the proper moment saves the crops from the greatest calamity that they dread, that is, lack of rain. By assuring the proper degrees of moisture in the soil at the very moment when it can give the best results, and in the necessary quantity for the different crops, a good harvest is always certain.

Instead of suffering from the fluctuations of the varying seasons, that is, having one or two good years, with five or six middling ones, and then two or three bad ones, the harvest is good every year, and occasionally, when the season has been especially favourable, it may be exceptionally good.

For the cultivation of Indian corn, potatoes, tomatoes, and the usual vegetables, the water required varies from 7000 to 8000 cubic metres per hectare (245,000 to 280,000 cu. ft. per acre), and is applied in "rotation" every 7 to 8 days at the rate of 400 to 500 cu. m. per hectare (14,000 to 18,000 cu. ft. per acre) per irrigation. In all cases, the cost of the water is more than repaid and the profit is greater than with no irrigation.

These examples, which may have a direct application to American agricultural conditions, are sufficient to give an idea of the quantity of water required for the ordinary cultivation (grass, cereals and ordinary vegetables) and of the financial results that may be obtained by the use of water. Besides, they prove the fact that irrigation gives to agriculture an almost certain revenue, putting it beyond any great fluctuations and completely avoiding the losses of bad years.

Thus, from the point of view of the farmer, irrigation is undoubtedly a great success.

Financial Aspect of Canal Construction. Unfortunately, the same cannot be said for the Canal Administration. Except for small irrigation plants—like "tanks" and "infiltration tunnels", made by private landowners, which are a great success from the very beginning—because private people will only construct easy works and will carry them out with greater economy than a large corporation—it is sad to ascertain that all large irrigation canals are never a great financial success; even under the very best circumstances they pay only the working expenses and leave a very small margin, 1 to 2%, for the capital invested, unless hydro-electric power can also be combined with irrigation.

The reason is that it is not alone sufficient to build a canal carrying a large volume of water in order to make it a success; it is necessary to be able to sell this water, that is, find the farmers ready to use it. But, as mentioned above, before the water can be disposed of, the distributing ditches must be prepared and the land properly leveled; then the farmers must learn how to apply the water to the land, at the precise moment and in the quantities best suited for the growth of plants in each kind of soil; they must decide which crops are the most profitable in each district; and furthermore, where the land is not very permeable, it is necessary to prepare drainage ditches in order to get rid of the surplus water, which, otherwise, by stagnating, might damage the vegetation or produce an excess of parasitic plants or cause water-logging of the land.

All of this requires experience, time, and capital, and so the Canal Administration is not able to sell all its water until many years after the canal is completed. In the best cases, it takes from 20 to 30 years—but generally much longer—to dispose of all the water of a very large canal.

The Marzano Canal, which crosses the province of Cremona—where irrigation has been practiced since the Middle Ages, and all the distributing ditches were already in service when the main canal was built, in fact, its function is only to increase the flow of the old irrigation canals—required fully 30 years before all of its 30 cubic metres per second of water were disposed of; and yet the conditions were most favourable. The Villoresi Canal, also in a region where irrigation is very well developed and has been practiced since the 12th century, has not

yet disposed of all of its water after 40 years of existence; and the financial conditions of its Administration are far from being prosperous. All the other canal administrations are practically bankrupt or nearly so.

Necessity for National Aid for Irrigation Canals. This is the reason why the Italian State helps all these undertakings. Irrigation puts under cultivation large tracts of land which have very little value or are almost sterile; and part of the population that now emigrates can find profitable employment in the cultivation of this land, and so increase the national wealth.

Italy has an increase in population of almost one million inhabitants per year, of which about 500,000 are obliged to emigrate. Some 300,000 go to North America, 100,000 to Central Europe, while some 80,000 go to Argentina and 20,000 to other countries around the Mediterranean.

To moderate this exodus, which is not beneficial to the Nation, the State encourages irrigation by granting a substantial subsidy, already mentioned, of 3% per year for a period of 10 years on the capital spent in the construction of the main canal and its principal branches; 2% per year for the following 10 years, and 1% for another period of 10 years. Then the subsidy ceases. But if the canal is arranged in such a way as to help in the control of the flood-waters—as when, for instance, impounding reservoirs are also built—then another subsidy is granted for this purpose, in the proportion of 10% to 30% of the capital expenditure. For instance, for the Tirso reservoir and canal, estimated at about 20 million francs ($4,000,000), the State, besides the usual annual grants, pays 3 million francs more because of the benefit derived from a better regulated discharge of the river, which prevents inundations in the low-lands. It also grants another $30,000 per annum for 50 years as a help for the irrigation canal, so that the water can be sold to the farmers at not more than 32 francs per hectare per year ($2.75 per acre). After 60 years, all the works become the property of the State.

On these lines, the Canal Corporations can derive a modest benefit from their enterprise.

CONCLUSIONS.

Irrigation Most Beneficial for the Farmer. Long experience with Italian agriculture—confirmed during the last fifty years—teaches us that irrigation is very successful in preventing the risk most dreaded by the farmers, that is, the complete failure of crops in years of drought.

In the irrigated districts, even where the price of water is high and thus has to be applied most sparingly, it is always possible to gather a crop sufficient to pay all expenses and still leave a small margin of profit for the farmers, even during the worst years. Thus, irrigation acts as a kind of insurance against the risks of drought, and from this point of view it is undoubtedly a great success.

Then, during years of normal conditions, irrigation causes a more complete growth of the crops—which are, consequently, of better quality for the market—and generally realizes double the profit given by non-irrigated lands. Even if only grass is grown, provided that water for irrigation does not cost more than 25 to 30 francs per hectare per year ($2.05 to $2.50 per acre), the financial results from such lands are at least double the usual. If cereals or common vegetables can be cultivated, the financial result is nearly three times as great, and if the land can produce fruit, especially oranges and lemons, then it is increased up to four or five times.

This explains why in Southern Italy, where there is an excess of sunshine in comparison with the normal rainfall, water is so precious and all possible schemes for collecting it for irrigation find a ready application, and why landowners—generally so indifferent or reluctant to invest money in improvements—are always eager to apply irrigation wherever possible.

This brings us to the conclusion, that from the point of view of the farmers, irrigation, when properly applied—that is, by rational cultivation, aided by the application of water, but not in excess—is decidedly a great success.

Irrigation Not a Success for the Canal Administration. The same cannot be said for irrigation when considered from the point of view of the Canal Administration, especially if the

works are on a large scale and the quantity of water to be disposed of passes, for instance, 10 cubic metres (350 sec-feet) per second. Owing to the time necessary for the farmers to prepare their land for irrigation and to acquire the necessary experience as to the quantity of water best adapted for that specific land and for the different crops, the water for irrigation is disposed of very slowly. Under the best conditions this trying period lasts from 10 to 20 years, and for the large irrigation systems it reaches 30 or more years.

Necessity for State Aid to Irrigation Schemes. This is the reason why the Italian Government grants annual subsidies of 3% (of the capital expenditure on the irrigation works) for the first 10 years, 2% during the following 10 years, and 1% for the last period of 10 years. But in special cases this is not sufficient, as now all the easy projects have been carried out and there remain only the costly ones. So at present a new law is before the Italian Parliament which proposes to increase these grants up to 60 years, and even to lend money at 2% per year, repayable in 50 years, to any farmer who needs it for adapting his land to irrigation.

This may seem extravagant: but taking into consideration the rapid increase of population and the general welfare in all the regions where irrigation is applied, the result proves to be sound political economy. In fact, the State, by the higher taxation and all the thousand sources by which the Exchequer is fed, soon gets back the money advanced, and receives still greater benefits from the higher standard of life and welfare of its citizens.

Irrigation has been, indeed, one of the main causes of Italy's rapid advancement in recent years; without it, a large portion of its population, especially that in the Valley of the Po, would have been obliged to emigrate. Instead, thanks to the rapid extension of irrigation, this population remained and made Italy what she is now, "The Garden of Europe".

This policy, which gave such good results, is going to be extended to the Southern Provinces of Italy, where, owing to the drier and milder climate—identical to that of California,—it will be possible to get even better agricultural results. But results will be even higher from the social point of view, as the

rather backward portions of the population, which now emigrate in such large numbers, will find better conditions of life at home and thus remain at home and contribute to the increasing prosperity of Italy.

Conclusions. The conclusions of this paper are that:

(a) Irrigation is, decidedly, most beneficial to the farmer: besides acting as an insurance against failure of crops in bad years, it generally doubles or more than doubles the normal crops; or it permits of the cultivation of crops of higher commercial value. It represents, also, a very important factor of progress for the district in which it is applied.

(b) But it is not equally beneficial for the corporations that carry out the irrigation works, because generally many years are required before all the water can be disposed of, and thus there is a dead loss for a period of about 20 years, or even more, during which the State must grant some subsidy.

(c) However, the State receives great benefits from the irrigated lands in the form of increased revenue from land and other taxes, and also in the general welfare of its citizens. So it is only just that the State should either carry out these works at its own expense or grant some substantial financial help to encourage irrigation projects, provided, of course, that they are properly laid out on scientific lines and sound financial bases.

(d) Thus, all such projects should receive the most cordial support from all citizens; as they all, directly or indirectly, reap some benefit from a better cultivated land, from an increased rural population, and from the higher standard of life which prevails in irrigated districts and which produces contentment and social peace.

This explains why scientific irrigation is of such great importance in Italy and why the Government encourages and helps, by all possible means—including substantial grants and loans at low interest,—all carefully prepared projects, aiming at the better utilization of its water resources for the more intense cultivation of land by means of irrigation.

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DISCUSSION

Mr. Adams.

Mr. Frank Adams* (by letter) stated that Professor Luiggi's paper is of very great value to irrigation engineers and specialists in the United States and should have a wide circulation. It recalls Dr. Elwood Mead's valuable report on "Irrigation in Northern Italy" written a decade ago.

The author's paper has special application to California because of the well-known similarity of California to Italy. With conditions of rainfall, climate, and seasons almost identical, Italy evidently is far in the lead of California in irrigation works and institutions, and in the results obtained in the more general branches of irrigation farming; notwithstanding the fact that some portions of Italy still continue to use crude and inefficient mechanical devices having their origin in preceding centuries. Italy has the great advantage of irrigation heredity and environment, and it hardly is likely that the general California irrigation farmer will acquire the skill, or combine with it the laborious application of personal effort of the Italian irrigator, for a number of decades to come. Nevertheless, in some sections of California (particularly in the southern California citrus orchards, but also to a less extent in parts of the plains and lower foothills of the San Joaquin and Sacramento Valleys) irrigation practices apparently approach in skill those of the Italian irrigator. Possibly it is an advantage to California that it is not yet necessary here to change the slope of meadows from north to south, in order to better the exposure and to produce the utmost yield;

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Mr. Adams.

but the willingness of the Italian irrigator to perform that task when advantageous should suggest to the American irrigator the great value of manual labor in increasing the returns from irrigation farming.

It is difficult to compare costs and profits from irrigation farming in Italy and in California, without having a definite measure of the relative purchasing powers of a dollar in the two countries. However, it is known that a dollar will go much farther in Italy than in the United States; so that when we find higher irrigation costs in Italy, as measured by our money, we must conclude that the Italian irrigator not only invests more in getting ready to irrigate than does the irrigator in California, but also that he generally reaps a larger profit per acre. For instance, if Italian irrigators invest \$40 to \$60 per acre in the preparation of land for irrigating general field crops, as the author states is done under favorable conditions, they must obtain much more profit for their investment than the mere difference in the purchasing power there and here of the money expended. Here \$30 per acre for preparing land for irrigating alfalfa under favorable conditions is considered a top figure; but it would cost the average western irrigator considerably more than double that to prepare his field as the *marcita*, or super-irrigated meadow, is prepared in the Valley of the Po.

In northern Italy, the annual cost of water under State canals is said by the author to be about \$1.60 per acre, with the cost under the great private canals about twice as much. This charge pays for about 4 acre-feet, of which about one half is wasted through non-use in the winter months. The average use in California and throughout western America is much more than 2 acre-feet per acre per annum, although 2 acre-feet per annum is about an average use for field crops in California where the rainfall corresponds to that in the Valley of the Po. The money cost for this water-supply, for general irrigation farming in the western United States, generally is less than in Italy.

The higher cost of water in some of the citrus sections of Italy (24 to 36 cents per 1000 gallons) while greater than in California is not surprising to those familiar with costs in some parts of this State. The highest annual charge known of in California (in San Diego County) is \$70 per miner's inch continuous flow, which is less than 2 cents per 1000 gallons if the water were used all the year. In some cases in San Diego County (which is the only California locality where irrigation water is sold by the one thousand gallons), rates of four or five cents per one thousand gallons are charged; and in acreage sub-divisions where irrigation is practiced in a limited, non-commercial way, rates as high as 20 cents per 1000 gallons have been fixed under public authority. Professor Luiggi states that under the high costs in Italy the annual use of water for irrigation is only about 0.6 to 0.95 acre-feet per acre. In some California citrus orchards an equally high duty for the water is attained, yet the annual cost of the water does not average over \$7.50 per acre for gravity supplies and \$12 per acre for pumped supplies.

Possibly the feature of greatest interest in the author's paper, to

Mr. Adams. those in the western United States, is his discussion of the financial aspect of canal construction and of the necessity for National and State aid to irrigation. The fact that commercial irrigation enterprises in Italy have been no more profitable to their investors than in western America and that the Government has found it desirable to lend its aid in a country so thrifty and so long established as Italy, must bring encouragement to those who believe that some kind of National and State aid to irrigation is the next step in America.

As the author points out, Italy is giving Government aid to irrigation in order to prevent emigration; or in other words to retain her people on her own soil.

If it is advantageous to Italy to take such means to keep her people at home, why is it not equally advantageous for the United States or for California to do things that will build up settlement in our irrigated regions, even if this involves going farther than Italy has done? Already we have some Government irrigation construction, but this is not now, and is not likely to be, sufficient to meet legitimate and justified demands. With private construction practically stopped because of being unprofitable, we are thrown back on community effort, largely on irrigation-district organization.

Probably public opinion in this country would not now sanction Government subsidies to private irrigation companies such as those allowed in Italy, yet some kind of financial aid, as by the purchase of their securities, has been seriously advocated to communities organized into irrigation districts and supervised by the State. By the subsidies granted, Italy insures irrigation development; and by the conditions of the subsidies, the property eventually passes to the State. As the author points out, Italy goes still farther and in parts of the country where capital is hard to obtain lends money to the farmer at low rates of interest, the principal to be repaid in 30 to 50 years. The Government then follows up this aid by giving advice to the farmer, by approving plans of proposed improvements before the improvement is begun, and by holding back payments on the land until they are actually needed. This method of approaching the problem of giving aid to settlers under irrigation projects is different only in degree from plans followed in other countries, notably Australia, and from plans now being suggested for the western United States.

Mr. Mead. **Mr. Elwood Mead,*** M. Am. Soc. C. E. (verbally), referring to Dr. Luiggi's statement as to Government aid given to companies—such as loans at 5% but requiring only 2% per year the first five years, 3% per year the second five years and so on until the full 5% per year is paid after 15 years—stated that he had received a letter from Dr. Luiggi recently which states that but little material progress is made so long as the State confines its aid to the irrigation companies alone for the purpose of constructing irrigation systems, and that full benefits are

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* Prof. Rural Institutions, University of California, Berkeley, Calif.

Mr. Mead.

secured only when such aid is extended also to the individual farmers in assisting them to prepare their land for irrigation. This consideration is important in the United States because here settlers have been left to struggle with greater difficulties in developing their farms than are found in the older countries. A point has been reached at which unaided development is checked, and in order to get the best results and to prevent failures of the individual farmers, we ought to include aid to the farmer himself as a feature of our irrigation development.

In reply to a question, Mr. Mead stated that in Italy drainage is carried out by local municipal organizations, corresponding to private companies in this country. The Government each year offers prizes for the best irrigation works and competition is keen, more for the prestige given by the award than for its money value. In the Valley of the Po the rainfall averages 45 inches per year and there is no alkali, because the alkali salts have been washed out by natural means. Many of the canals are in gravelly soils where much seepage occurs, but the seeped waters collected by the drains often can be sold at sufficiently high prices to pay the cost of the drainage works.

Mr. Norboe.

Mr. P. M. Norboe,* M. Am. Soc. C. E. (verbally), stated that it should be made practicable for California irrigation districts to market their bonds under more favorable conditions than at present and thus reduce the cost of construction. At present the State passes on the feasibility of the project but the administration of irrigation districts is as yet vested in the hands of generally inexperienced directors; so that the approval by the State officers is of little value as a protection to the investor unless some means be provided whereby the State can also supervise the construction work, in order to see that it is being done in accordance with the plans. While the State has the power to require that feasible plans be submitted, the investor is not protected as long as the districts are left free to carry out the work in accordance with the plans or not.

The first validating act was passed in California in 1911. Prior to that, irrigation-district bonds were not available for many purposes, as were municipal bonds, and this hindered the sale of the former. The validating act provides that in order for irrigation district bonds to be registered by the State, the project must be approved by the Superintendent of Banks, the Attorney General, and the State Engineer. In the following Legislature it was brought out that this method was not sufficient. While a district may be organized satisfactorily under the law and while the project may be feasible and the security ample, and while good plans and sufficiently high estimates of costs may be made—still there is no authority provided to see that such plans are followed in the construction. After the approval of the bond issue by the State, the districts could change the plans or could neglect the enforcement of the specifications and permit faulty work to such an extent that the

* Assistant State Engineer, Sacramento, Calif.

Mr. Norboe. district might become bankrupt. The best legislation that could be secured at that time was to require that the plans for all work to be constructed from moneys acquired by bond sales should be submitted to the State Engineer and also that reports of construction should be made to him. However, as yet, there is no authority by which the State Engineer can compel the district to follow the plans which have been approved. He has authority to inspect but cannot stop or change the construction work, and of course such authority is useless when its violations cannot be punished.

Referring to the author's description of automatic spillways used in Italy, Mr. Norboe stated that they had been introduced recently into American practice.

Gen. Marshall. **Gen. Wm. L. Marshall*** (verbally) stated, in reply to a question, that he had seen automatic siphon spillways used on some of the projects of the U. S. Reclamation Service and had himself designed one of a similar type in which a movable crest rises and falls with the water surface. The objections sometimes made to these siphons are that they may discharge a large volume of water into the streams suddenly, and thus damage the stream-channel. A type of spillway in which the discharge is increased gradually may be preferable in some cases. As much as 2000 to 3000 cubic feet per second may be discharged by some of these siphon spillways.

Mr. Hopson. **Mr. E. G. Hopson,**† M. Am. Soc. C. E. (verbally), stated that the automatic siphon spillway on the Orland Project, California, is working satisfactorily and that no damage has been done there by the sudden inrush of the water.

He commented on the author's discussion of State credits extended to irrigation companies, and suggested that some such method could be adopted in the United States with great benefit. Here the development now stops short of being complete and something must be done to enable the farmers to develop their lands within one or two years, so that returns from irrigation can be secured more quickly than at present.

Mr. Grunsky. **Mr. C. E. Grunsky,**‡ M. Am. Soc. C. E. (by letter), stated that there is great similarity of conditions between the irrigated regions of Italy and those of California. It is interesting, therefore, to find that Dr. Luiggi reaches conclusions which agree so well with the results to be noted in the United States. When he says that under the most favorable conditions it will take 20 to 30 years to bring all the water of a large canal into use, he is but voicing the general experience in this country. Such cases as that of the Imperial Canal, where there was an early demand for a large part of the canal capacity, are exceptions to the general rule. We are forced to admit in this country, as well as in Italy, that from the standpoint of the canal owners, large irrigation projects

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† Recently Supervising Engineer, U. S. Reclamation Service, Portland, Ore.

‡ Cons. Engr., San Francisco, Calif.

Mr. Grunsky.

rarely are successful financially. However, they are a benefit to the land-owner and to society; and there is no natural resource of any country which in the interest of all the people should be developed so early and so fully as its water-supply. The supply is replenished annually by nature—and by its use for power, fuel is conserved; by its use for irrigation, the productiveness of the soil is increased greatly; and by its control in streams and in artificial canals, avenues of commerce are created and improved.

Everyone knows how seriously the irrigation securities of the United States have been discredited in the world's markets. This was not because there are not many projects fully able to meet their financial obligations, but because the ultimate purchaser of irrigation securities has no certain means of discriminating between those which are good beyond question and those which are doubtful.

In the United States we now have entered upon the same policy of Government aid to irrigation development which has been a success in Italy. For the present, this has taken shape in the work done by the U. S. Reclamation Service in the Western states, through which works are constructed not only for the irrigation of the public domain (which thereafter becomes available to the farmer, with their water-tax added to the cost of the land), but also, upon occasion, for the irrigation of privately-owned lands, with a suitable provision in every case for a return of the cost of construction in the course of time. Through the Reclamation Service, by the waiving of interest on the cost of construction, the United States makes a direct financial contribution in aid of irrigation development.

The principle of extending financial aid to irrigation development having been recognized as judicious by the Federal Government, it is to be hoped that at an early day it will be adopted also by the individual States. At present the States endeavor to protect the securities under the Carey Act and those of other irrigation districts by means of more or less unsatisfactory supervision—exercised by commissions composed of certain State officials, whose acts carry with them no responsibility by the State, and therefore have little or no effect upon the standing in the world's financial markets of the irrigation securities passed upon.

That condition will be changed when the State assumes full responsibility: when after due investigation the State approves a project and (upon favorable vote by the people who are to be taxed for it) issues State bonds to cover its cost; and thereafter, through a properly constituted Department of Public Works, sees to it that the works are constructed as planned. Such securities issued by the State, not being dependent upon the success or failure of individual projects, would command a fair price in the money market; and irrigation districts would not, as now, have to pay excessive prices for the construction of their systems.

It is some satisfaction to the American engineer to learn from the author that the thin arch dams and the rock-fill dam, both of which

Mr. Grunsky. made their first appearance in this country, have come to be recognized as standard types of high dams in Italy.

Mr. Duryea. **Mr. Edwin Duryea, Jr.*** Mem. Am. Soc. C. E. (by letter), stated that Professor Luiggi's paper presents a large fund of exact and valuable irrigation data within a very small compass; he never has seen its superior in this respect.

It is gratifying to the engineers of America (where very little irrigation is older than forty or fifty years) to learn that even after twenty-five centuries of irrigation in Italy, it still is the universal opinion there that irrigation is a permanent benefit to the irrigating farmer and to the State and does not result (when rightly practiced) in harm to the lands.

It is of interest to learn that in Italy irrigation often is profitable up to costs for the water as high even as 36 cents per 1000 gallons, or $117 per acre-foot, a very high cost in America even for city water-supply and far above permissible costs for irrigation water. This, no doubt, is due to the intensive methods of cultivation and careful use of water in Italy, seldom equalled in America.

It is apparent that while irrigation has been carried on in Italy in a small way for centuries, it is only within the past fifty years that large irrigation developments have been undertaken, such as require large dams and reservoirs. It appears also that even with the present double use of the water for both electric power and irrigation, commercial companies carrying out such large projects seldom are financial successes in Italy, and that State aid in some form is a necessity. This usually is the experience also in California and the western United States of America, where the development of new large irrigation enterprises by commercial companies practically has ceased—and such new enterprises now are carried out either by mutual combinations of the irrigators, who after completion get their irrigation at cost and without the addition of a commercial profit; or by the United States Reclamation Service, which ultimately is repaid for the development by the irrigators.

It is of interest to learn that earth dams (the most common form of dam in America, and one which is well liked) are not in favor in Italy, where most dams are of masonry. The growing use of "rock-fill dams" in Italy, because of their low cost and their resistance to earthquake damage, is of interest; but it is apparent that the Italian rock-fill dams are much more elaborate structures than most of those in America.

In view of the long-continued successful irrigation of Italian lands, it would be of much value to American engineers to learn how land damages from over-irrigation and from alkali have been prevented or remedied, and what is the final conclusion in Italy as to the extent to which drainage is, in general, a necessary accompaniment to long-continued successful irrigation.†

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* Cons. Engr., San Francisco, Calif.

† This inquiry is answered by Elwood Mead, M. Am. Soc. C. E.; see his discussion.

Paper No. 41

IRRIGATION IN LYBIA (Italian Colony).

By

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Professor of Hydraulic Engineering at the Royal University of Rome
President, Italian Society of Civil Engineers
Rome, Italy

LYBIA THREE YEARS AGO.

Lybia,—that is, the region round Tripoli and Bengasi, (Fig. 1) annexed less than three years ago by Italy—was in Roman times a most flourishing country, owing to a very advanced state of agriculture, aided by irrigation. However, under centuries of Turkish misrule, it had decayed so much that, what once was considered almost as the granary of Rome, had become a semi-desert land. Very few agricultural products were exported, and commerce had very little importance. Thus there were practically no harbours, lighthouses or other maritime works worthy of the name, no railways or roads fit for modern means of transportation, and the little traffic there was with the interior was done by camels or donkeys.

When the Italians occupied Tripoli, Bengasi and the smaller centres of population, only decay, misery and filth could be seen everywhere, and the inhabitants—about half a million—were ignorant of the most elementary notions of sanitation, for a large part nomadic by instinct and long tradition, and lived in a state of semi-starvation.

If the region had to be of use for Italian settlers, it was necessary to remedy quickly this state of things. So the Government took at once vigorous measures for carrying out the most urgent works, and for developing them methodically, in combination with the development of agriculture on modern lines, upon which depends the future welfare of Lybia.

PUBLIC WORKS CARRIED OUT BY ITALIANS.

Means of communication with Italy and with the interior were the most needed; so important harbour works and landing jetties were begun immediately in Tripoli, Bengasi and the smaller settlements of Derna, Homs, Zuara, etc., and connected by a system of lighthouses, semaphore stations, and lines of telegraphic or wireless communications as aids to navigators.

At the same time, two systems of railways—one starting from Tripoli and the other from Bengasi—were laid down in the trail of the advancing troops, towards the interior, up to the foot of the table-lands of Garian and Cyrenaica respectively; and good ballasted roads, fit for motor traffic, were extended for hundreds of miles in the interior, connecting the smaller centres of population with the railways.

The works already completed comprise—besides the landing-jetties—several break-waters, one of them at Tripoli being 2,500 feet long, extensive dredging in all the harbours, nearly 150 miles of one-metre gauge railway, water works for the principal towns and smaller centres, hospitals, lazarets, disinfection stations, schools, markets and other municipal works, such as the lighting and paving of streets, etc.

All these works have been carried out according to plans prepared by the Author in view of the future development of agriculture in Tripolitania and Cyrenaica, not only to equal what it must have been in Roman times, but as it can be further improved by modern methods of cultivation, aided, as it was in ancient times, by extensive irrigation.

But to appreciate the value of these improvements, some details of the natural and especially of the climatic conditions of the country are necessary.

NATURAL CONDITIONS OF LYBIA.

Tripolitania, for the most part, is a flat country, slightly elevated above the sea-level, with a rather hot and dry climate. Almost all the rain falls during the winter months, from November to February, at the rate of 20 inches near the coast, 10 inches near the table-land and hardly any further inland. That part of the country within the line of the 15 inches rainfall is sandy, but adapted for the culture of cereals of rapid growth,

and for the breeding of sheep and goats. Thanks to the abundance of sunshine, even in winter, good crops of cereals can be raised in the period from October to March or April.

Cyrenaica is an undulating plateau from 1,000 to 2,500 feet above sea-level, with a rainfall of from 15 inches near the coast to 30 inches on the table-land. Thus cereals, fruit trees, olives, vines, etc., can be cultivated and give good profits. Besides, the date-palm trees thrive all over the country, and form an important item in the agriculture of Lybia, as a palm-tree can give a net profit of one to two dollars per year. But they must be protected from the summer drought by the aid of irrigation; also other crops can be grown under the shelter of the palm-trees, provided they are irrigated during the summer.

Thus the future of Lybia depends largely on irrigation.

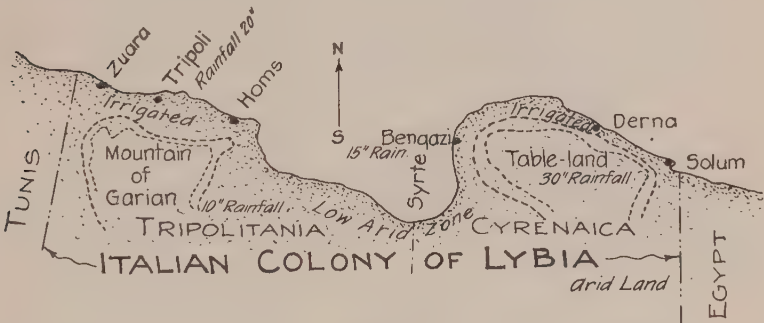

Fig. 1. (Luiggi)

IRRIGATION WATER FROM WELLS.

At present, irrigation, as applied by the natives, is very rudimentary, though quite ingenious.

The soil being very permeable, all the rain-water percolates rapidly into the subsoil, where it collects, and has to be raised from wells. This makes the cost of the water rather high, and so special means for economizing it for irrigation had to be devised. The result is that special precautions are taken both for preventing too much evaporation and undue losses by percolation in the soil.

For this purpose, a very clever method, probably of Roman origin, is adopted generally to minimize evaporation. On the

area to be irrigated, palm-trees are first grown, and these—besides giving a good revenue—act as sunshades for the orange, olive, and other fruit trees planted under their shelter; these trees in their turn shelter the lucerne and vegetables grown on the surface of the soil, and which are directly irrigated. Thus on the same plot of land are cultivated three crops, and the water for irrigation is utilized to the fullest extent. The water is so carefully applied, and so thoroughly utilized, that one ordinary donkey is sufficient for raising from the subsoil the water necessary for the irrigation of almost two acres of land, corresponding to about four feet of water per year.

But this method is only applicable to limited zones in which the underground water-level is not more than 20 feet or 30 feet below the surface, otherwise it becomes too costly.

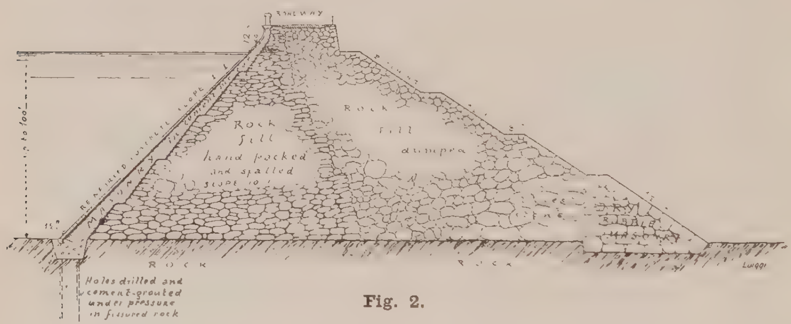

Fig. 2.

This same method is also used with success in some parts of Sicily and on farms of a few acres in extent. Now windmills of American make are introduced in order to raise the water more cheaply.

IRRIGATION WATER FROM RESERVOIRS.

For irrigation on a larger scale, underground water would not be sufficient, and, as there are no running streams in Lybia, it is necessary to collect the rainfall, and store it up in reservoirs. This has been done since time immemorial, and the ruins of ancient cisterns of Greek origin, and dams and aqueducts of Roman construction can be seen in many places. Some of them are now being restored, and will soon be brought again into use.

In the meantime, new reservoirs are being considered, and will shortly be started. They will be especially of the "rock-fill" type (Fig. 2), which are cheap and easy to build and keep in good repair. When they have slopes of 1 in 2, the rock-fill dams will be able even to resist earthquake shocks. As labour in Lybia is scarce and inefficient, and good materials are not easily found, these rock-fill dams—that can be built almost entirely by mechanical means,—are cheaper, safer and quicker to construct than earth or masonry dams.

This type of dam is very common in the western States of America, which are also subject to earthquakes, and has been adopted with success in Italy in the valleys of Cenischia,

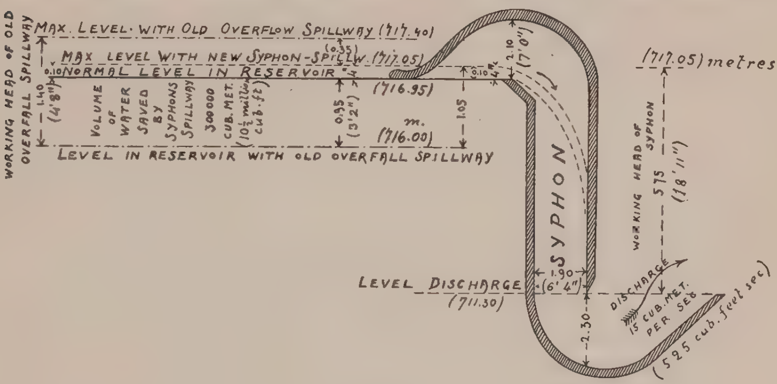

Fig. 3. *Luiggi*

Biaschina and Devero. The last mentioned dam is the most important, as it is 110 feet high, impounding 13 million cubic metres of water (455 million cubic feet or nearly 11,000 acre-feet) at a cost of only $160,000.

AUTOMATIC SYPHON SPILLWAYS.

A special feature of the new reservoirs will be the automatic syphon spillways, applied by Signor Gregotti to many dams and canals both in Italy and abroad.

The syphon (Fig. 3) is generally a square tube built of ferro-concrete, and capable of discharging from 1 to 15 cubic metres (525 cubic feet) per second, according to section and head, which can vary from 1 to 7 metres (3 to 23 feet) in height.

If larger discharges are required, as many as ten syphons have been placed side by side. As soon as the water-level in the reservoir exceeds the normal by 2 or 3 inches, the syphon becomes automatically primed, thanks to the shape of the upper lip, and begins to act with full discharge until the level becomes lower than the upper lip of the syphon, when the air gets in, and the flow ceases.

The velocity of discharge is due to the difference of level from the reservoir down to the outlet, whilst in the ordinary overfall spillways, the head is limited by the height of the falling water over the sill. The syphons, moreover, act better and are less expensive in construction than ordinary spillways.

For example, in the Lagolungo reservoir, near Genova, the old overflow spillway required a head of 1.40 metres (4 ft. 8 in.) to discharge the freshets, and several million cubic feet ran to waste over the spillway after each storm.

Now a battery of 10 syphons, with an internal cross-section of 1.90 metres square (6 ft. 4 in. square) and a working head of 5.75 metres (18 ft. 11 in.) has been provided, capable of discharging 150 cubic metres per second (5,250 cu. ft.) and at the same time the sill was raised by 0.95 m. (3 ft.). Thus an additional volume of 300,000 cu. metres (10½ million cu. ft.) can be impounded, and this is a very important advantage in a place where water is very valuable.

It was moreover proved that the syphon gave a discharge of 150 cu. metres per second when the water rose to 4 inches over the lip (Fig. 4), which was 14 in. less than formerly with the old spillway, thus reducing correspondingly the water-pressure against the dam.

The greater volume of 300,000 cu. m. of water, thus impounded, represents an income of at least 15.000 francs ($3,000) a year, and capitalized at 5%, gives a total of 300,000 francs ($60,000), equal to at least six times the cost of the new spillway.

Of these automatic syphon spillways, there are more than one hundred on the Italian dams and canals, and one for a discharge of 500 cubic metres per second (17,500 cubic feet) is soon to be applied to a hydro-electric plant in Norway. All give complete satisfaction.

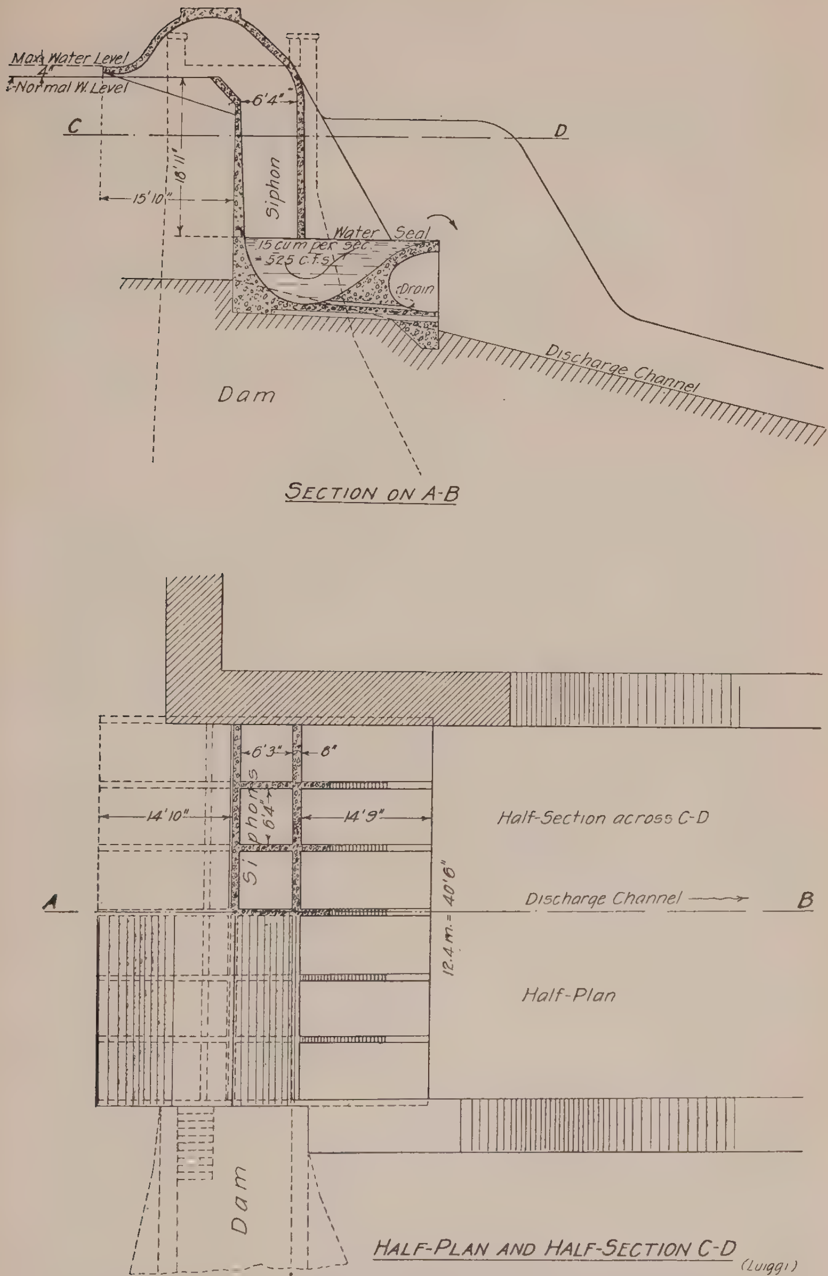

Fig. 4.

Automatic Syphon Spillway at the Lagolungo Reservoir, discharging 5250 cu. ft. per second.

THE FUTURE OF LYBIA DEPENDS ON IRRIGATION.

As already said, ruins of numerous dams, cisterns, and aqueducts have been found in Lybia. This proves that at one time, agriculture supplemented by irrigation, must have flourished, as is also proved by the important and costly temples, of which we still find traces, and which could never have been built had not the agriculture been so flourishing as to leave plenty of benefit. This demonstrates that the future of Lybia depends on the development of agriculture, aided by scientific irrigation, that is, by reproducing in our own time, on a larger scale, and with more powerful means, what the Romans were able to do successfully nearly 2,000 years ago.

DISCUSSION

Mr. Duryea. **Mr. Edwin Duryea, Jr.,*** M. Am. Soc. C. E. (by letter), stated that it would have been of general interest if Professor Luiggi had added to his valuable short paper descriptive of irrigation in Lybia a brief statement of the magnitude of the Lybian irrigation problem. No doubt many European engineers have this knowledge already, but most American engineers have only vague ideas of the geography of Lybia. The map, Fig. 1, includes no scale, but an atlas shows that the air-line distance between the northeastern and the northwestern corners of Lybia, at the shore of the Mediterranean, is nearly 800 miles, or greater than the distance between New York City and Chicago.

It is to be regretted that Professor Luiggi did not state the area now under irrigation, the area of irrigable land not yet irrigated, the total ultimate area of land it is hoped will be brought under irrigation (in view of the available water-supply and the justifiable cost), and what total population it is hoped that Lybia can support by the aid of these irrigated lands.

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Paper No. 42

RECENT DEVELOPMENTS OF IRRIGATION IN INDIA.

By

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INTRODUCTION.

1. Apart from irrigation, agriculture in India is entirely dependent on the rainfall which is confined chiefly to what is known as the south-west monsoon, commencing generally about the end of June and terminating about the end of September. In certain tracts in the south-east of the Peninsula a further important contribution occurs in what is known as the north-east monsoon, commencing about the end of October and ending about the middle of January. It is to the occasionally deficient, or in rarer cases, to excessive, precipitation in these two periods that all famines in India have been due.

2. The average annual precipitation varies greatly in different localities; for example, from a maximum of upwards of 400 inches in the Eastern Himalayas, and from 250 to 100 inches in the Western Ghats, to as little as from 10 to 5 inches in the Sind and central deserts; and it will be realised how such a diversity of climatic conditions dominates agricultural practice, and not only the need for but also the efficiency of irrigation works in different parts of India.

3. Much of the precipitation in the higher Himalayas, say above R. L. 14,000, falls as snow and is retained as in a vast natural reservoir until the following warm-weather months, April to June. It is from this source that all the principal rivers of Northern India derive their perennial supplies, viz., the Ganges and Jumna flowing south-east, and the Ravi, Sutlej, Chenab, Jhelum and Indus flowing south-west. It is from these

rivers that all the most important perennial irrigation works of the Punjab and the United Provinces derive their supplies.

4. The precipitation on the Western Ghats, on the other hand, all occurs as rain, chiefly during the south-west monsoon, and runs off quickly. The Godavari, Kistna, and Cauvery rivers, all flowing east, have their sources in this tract and feed important irrigation works in their deltas on the Madras coast.

5. A considerable tract on the north-east of India comprising the Provinces of Bengal and Assam with part of Orissa, in which the annual rainfall averages from 75 to 50 inches, is largely independent of irrigation.

6. In the great central tract, however, with an average annual rainfall of from 50 to 20 inches and less, agriculture without irrigation is very precarious, while the river supplies, being equally dependent on the rainfall, are liable to fail most when most required.

7. The natural conditions which I have thus briefly sketched have been and will remain the permanent dominating factors of irrigation progress in India. Thus we find the most important and profitable irrigation works are those dependent on the perennial snow-fed rivers rising in the Himalayas, and their irrigation, where the river supplies are harnessed by permanent works, is more or less continuous throughout the year, two separate crops being raised. The most important of these Himalayan rivers, the Indus, however, is not yet harnessed, and although important irrigation is done from it both in the Punjab and in Sind, it is all done by inundation canals, i. e., by artificial channels in which the supply available is dependent on the natural levels in the river during the flood season, June to October; on these canals only a single crop, chiefly rice, millet, or cotton, can be raised in the year.

8. Similarly, the irrigation works in the Madras deltas being entirely dependent on rain-fed rivers are chiefly single-crop canals; but the rainfall in the Western Ghats is so large and generally dependable that their supplies during the flood period, though fluctuating, never fail badly, and the crops dependent on them are generally secure; these canals are among the most successful and profitable in India.

9. In the Central tract the unreliability of the river sup-

plies has been met by artificial storage in reservoirs, and it is in this tract that most of the Famine Protective Works are situated.

Relation of Irrigation to Total Cultivation.

10. The area of India which is administered by the various Presidency or Provincial Governments under the general control of the Government of India is roughly about 620 million acres.

Of this area about 230 million acres are Forest Lands or lands not available for agriculture. Another 115 million acres are culturable waste or lands not yet broken up for agricultural purposes, and 55 million acres are annual fallows, leaving about 220 million acres annually cultivated, and of this area only some 41 million acres are irrigated.

These approximate figures vary each year, within certain limits, according to the nature of the seasonal rainfall, but may be accepted as fairly representing the average of the past few years.

11. The relatively large proportion of unirrigated to irrigated cultivation, nearly as 4 to 1, explains the liability to famine of greater or less intensity and extent to which India is still liable in spite of the fact that her irrigation systems rank among the largest in the world.

Recent Development.

12. Recent development of irrigation in India is to be traced primarily in the expansion in the total irrigated area which has occurred in recent years, and the following statement gives figures for the ten years ending 1912, which is the latest year for which complete figures are available:

	Million Acres	
1902-03	33	Average 34.
1903-04	34	
1904-05	31	
1905-06	35	
1906-07	37	
1907-08	40	Average 41.
1908-09	42	
1909-10	42	
1910-11	41	
1911-12	41	

The development of irrigation in this period measured by the difference in the first and last totals is about 25 per cent, while measured by the increase in the average for the last 5 years over that of the first 5 years of the period it is about 20 per cent.

13. These figures represent only the areas actually irrigated each year. A part of this area is double cropped, or land which having the advantage of perennial irrigation bears two separate crops in the year, and the total area of irrigation in any given year including double-cropped land, may be taken roughly as about 10 per cent in excess of the figures given in the above statement.

General Classification of Irrigation.

14. It is not to be supposed that the whole of this area is irrigated by irrigation works constructed or controlled by the Government; the classification of the 41 million acres irrigated in 1912 is approximately as follows:

From Government Canals	42 per cent.
From Private Canals	5 per cent.
From Tanks	13 per cent.
From Wells	25 per cent.
From other sources	15 per cent.

15. It will be seen that irrigation from wells ranks in area and importance next to irrigation from Government works. Irrigation wells are wholly the private property of the land owners, but construction is encouraged by the grant of temporary advances from public funds to the owners, which advances with interest at 4 per cent are recoverable by easy instalments. The Government further assists this class of irrigation by the loan to the owners of boring plant and the services of expert borers, both to make preliminary tests of the subsoil supply and to improve the supply in existing wells by tapping deeper water-bearing strata.

PROGRESS IN GOVERNMENT WORKS.

16. It is, however, mainly with progress under the head of Government Irrigation works that this paper deals, and Table I illustrates the progress as measured by the areas irrigated in this class of work for the period 1902-03 to 1913-14.

Measured by the difference of the last and first years of the period, the increase in the 12 years has been rather more than 26 per cent. Measured by the difference in the averages of the last and first half-periods, the increase has been 16.5 percent.

17. The classification of the State Irrigation given in Table I is that adopted for administrative purposes.

Productive Works, which account for roughly two-thirds of the total area of irrigation, are works which when projected were expected to more than pay their working expenses as well as to clear all interest charges on their capital cost within ten years of their completion: this constitutes the justification and is the criterion enforced for financing them from loan funds.

18. Table II gives particulars of some of the more important of this class of works now in operation.

It will be seen that the project anticipations as defined above have not always been reached, notably on the Kurnool Cuddapah Canal in Madras, and on the Orissa Canal in Bihar and Orissa, for the reason that the large annual rainfall makes this country largely independent of irrigation. The reason of the comparatively high profits realised on some of the Punjab Canals, e. g., the Lower Chenab, is that the tracts irrigated were formerly desert, paying no land revenue, and in these cases the canal is credited with part of the land revenue, now that the land is cultivated, as well as with the direct water rates.

19. All other classes of works are financed from Revenue Funds. No borrowed capital is invested in them. Of these, "Protective Works" are, as their name implies, designed primarily to afford protection against famine. They are not as a rule expected to return a direct profit, although indirect returns are anticipated from reductions in famine relief charges and in remissions of land revenue, as well as from the general support they afford to the agricultural status of the tracts they serve.

20. Table III compares the area irrigated by Government works with the total area cropped in each Province for the year 1912-13, and also the capital cost of the irrigation works compared with values of crops annually raised in the irrigated areas.

21. Table IV gives the works which were completed and brought into operation in the period under review.

22. Table V summarises the general results of all irrigation works under the several classes for the year 1912-13.

It will be seen that the Protective Works as a whole yielded a net revenue of 9.53 per cent on their capital cost and a net profit after deducting interest charges of 6.3 per cent. Protective Works on the whole did not cover interest charges by direct return, while the net revenue on Minor Works amounted to 4.39 on the capital cost.

23. Table VI gives the works now under construction, some of which are in partial operation though not yet quite completed. It will be seen that these works are expected, when fully developed, to increase the area irrigated by Government works by nearly 5 million acres.

Table VII gives the principal projects still under investigation.

24. This completes the general review of recent progress on irrigation works in India, and it remains to indicate such technical details of the recent work which may be of general interest to the Conference.

TECHNICAL DETAILS.

Points of Technical Interest in the Triple Project.

25. The most notable of the works now under construction, in point of scope and boldness of treatment, is undoubtedly the group of works in the Punjab, numbers 2, 3, and 4 of the list given in Table VI, which together comprise what is known as the Triple Canal Project.

A sketch map, Plate I, is appended, which shews the general scope of the scheme. The chief point of interest to Irrigation Engineers is the transfer of surplus supplies in the River Jhelum, for the utilization of which there was not full scope in its own valley, across two other rivers of first magnitude, viz., the Chenab and the Ravi, to irrigate lands in the valleys for which the natural supplies of those rivers were inadequate.

26. The transfer of water is of course not direct; thus, while the surplus supply of the Upper Jhelum is poured into the Chenab River it is not used in Upper Chenab Canal, which is the middle link of the Triple Scheme, but the natural supply of

the Chenab River, heretofore utilised in the existing Lower Chenab Canal, is hereafter to be taken by the Upper Chenab Headworks at Merala and the equivalent supply is to be made good to the Lower Chenab Canal from the surplus water of the Jhelum via the Upper Jhelum Canal.

On the other hand, the surplus supply of the Upper Chenab Canal is carried right across the River Ravi at Bulloki.

27. Considerable discussion arose with regard to this crossing of the Ravi River before construction commenced. The Project proposal was for a syphon to carry the Upper Chenab Canal water under the Ravi River and details of the design for the work are given and discussed in Buckley's "Irrigation Works on India", page 245, *et seq.*

The syphon was to be 1400 feet in length between the river retaining walls, with 8 vents 11½ by 10′, the base measurement of the concrete foundation being approximately 1500′ by 130′.

The foundation level was designed 23.0′ below river-bed level, 26′ below normal spring level, and 40′ below high-flood level in the river.

28. This design was eventually rejected on the grounds of expense and of the great difficulty and risk involved in getting in the foundations under such severe pumping, and a design was adopted for a level crossing by means of a masonry barrage across the Ravi, consisting of 35 spans with steel gates of 40′ clear width by 12.5′ height, of the counter-balanced type to lift 19.5′ or 5.0′ clear of high-flood level in the river. The Ravi flood discharge which has to be passed through the barrage is estimated at 200,000 cusecs. The syphon was estimated to cost Rs. 4,900,000 and the level crossing Rs. 2,600,000 only, or a saving in favor of the latter of Rs. 2,300,000.

29. Another item of technical interest connected with the Triple Scheme is the headworks of the Upper Jhelum Canal at Mangla. The site chosen for this work is in a sandstone bluff on the concave side of the sharp bend of the river, and a few hundred feet upstream of a natural boulder bar of long proved stability. The canal sill-level is designed so that full supply is obtained with water-level in the river at the level of this permanent natural bar, and in these circumstances it was decided to

dispense with a weir and under-sluices, which are the usual adjuncts of a canal head of this size. The Regulator consists of 20 spans 12 ft. wide, with gates in 3 sections to admit top water and so exclude heavy silt when the river is in flood; as the high-flood level rises to a height of 62 feet above the sill, the necessity of this precaution will be obvious. The roadway is 5.0′ above high-flood level and the total height of the work above mean foundation level is 77.5 feet. The width of foundation level is 74.0′. The gates are counterbalanced and fitted with individual gearing. The location chosen for the head regulator entailed very heavy cutting through the sandstone cliff for upwards of 2 miles, with a maximum depth of over 110′, involving 150,000,000 cubic feet of excavation. But the relative estimated cost of the work as sanctioned and of an alternate proposal for a weir lower down the river so as to avoid the heavy cutting was for the sanctioned design Rs. 33,000,000 and for the alternate design for a weir Rs. 44,000,000, or a saving of Rs. 11,-000,000 in favour of the proposal adopted.

30. In the first 40 miles the main line of the Upper Jhelum Canal skirts a low range of bare sandstone hills which are practically bare of all vegetation and from which the run-off proved far larger than had been anticipated when the scheme was first projected.

A revision of the estimate provision for cross-drainage works to meet this resulted in additions to the original estimate of no less than Rs. 9,675,000. The average annual rainfall of the tract does not exceed 45 inches, and it may be of interest to record here that the scale of run-off finally adopted in the revision, which was based on actual flood discharge observations, varied from 2400 cusecs per square mile for catchments up to 1 square mile in area to 1000 cusecs per square mile for catchments of 10 square miles in area—allowances which are considerably higher than have been generally given in past Indian practice in tracts of equivalent annual rainfall.

Merala Headworks, Upper Chenab Canal.

31. Plates II and III attached give cross sections of the weir and undersluices. The chief details of the work are as follows:

Level of the mean weir crest is 72′ above mean-river; bed length of weir between abutments, 8×500′ bays and 7×10′

intermediate piers, total length 4070′. The crest of weir is 1.0′ higher at the right abutment than at the left, on which flank the undersluices and canal head are situated.

The cost of the weir was estimated at Rs. 2,700,000, or at the rate of nearly Rs. 665 per foot run, which is high compared with other similar works in India. The section perhaps errs on the side of safety, but was designed specially heavy in view of former partial failures of the Narora and Khanki weirs, which, as originally built, and even as subsequently modified after partial failure, still are of considerably lighter section.

Details of these works will be found in Buckley's "Irrigation Works in India", pages 157 to 168.

32. The falling shutters on the weir crest are built of mild-steel angles and plates and are of what is known as the "Ashford" pattern, each 3.0′ wide by 6.0′ high; they are of the automatic release type, i. e., the release of the end shutter of each bay mechanically from the abutments or piers automatically releases the next and so on throughout the flight. There are other patterns, both earlier and later, of the same class also in use in India, the main object of the arrangement being to ensure release of the shutters even if they are topped by a flood. Previous to 1905, except for the automatic tension type described in Buckley's "Irrigation Works in India", pages 117 and 153, which are objectionable as being uncertain in their action, the shutters in general use on weirs in India each required separate release by hand, and this could only be accomplished without risk to the establishment before the water had topped them, a defect which led not only to unnecessarily frequent manipulation of the shutters for small freshets, but on certain occasions owing to the shutters not having been released in time, to their being topped by sudden and heavy floods, thus causing serious and costly damage to the weir structures.

Since the introduction of the automatic release there have been no such accidents to works owing to the shutters being topped, while accidents to the establishment, which were formerly by no means rare, have been very much reduced. The cost of the "Ashford" shutter is approximately Rs. 7-8-0 per square foot erected.

33. In the writer's opinion the Upper Chenab Weir section

is unnecessarily expensive and might safely have been reduced by about Rs. 100 per foot run; for example, the two rows of wells downstream of the crest wall are unnecessarily deep. The Chenab River sand, however, is extremely fine and treacherous and it must be admitted that it is better to be too liberal than the reverse in the design of a work of this importance, on which will depend such enormous vested interests in annual crop values.

34. The undersluices consist of 7 spans of 35.0′, or total clear waterway of 245 feet with 6 intermediate piers 11.0′ thick, or a total length between abutments of 311 feet. The gates are built of steel girders and plates with "Stoney" rollers and are counterbalanced and fitted with individual gearing.

The cost of the undersluices amounted to about Rs. 900,000 and the cost per foot run between abutments amounts to nearly Rs. 2900, inclusive of the gates, which cost, with gearing, approximately Rs. 40 per square foot of gate area.

35. The foregoing descriptions are given as examples of the latest type of headworks design in India, and as in the case of the head regulator and undersluices, it may be noted that individual gearing for each gate or sluice is generally displacing the former arrangement of a travelling crane operating the gates in turn; and though slightly more expensive, the individual gearing is more convenient and efficient and is generally considered to be worth the extra cost.

Upper Swat Canal.

36. The general scope of this scheme, now nearly completed, will be found in the statement, item No. 5, Table VI.

It is of interest technically on account of the bold engineering of its head reach.

The canal is carried through the Malakand Hill in a tunnel of which the following are the dimensions:

Length	11,235 feet
Width	18 feet
Height	13.5 feet
Slope	1 in 215

Coefficient assumed in Kutter's formula

$N = 0.025$

Calculated discharge

With depth 10.75	2180 cusecs.
Mean velocity	10.7 feet per second
With depth 12.5	2420 cusecs
Mean velocity	10.7 feet per second

The tunnel excavation was carried out from headings at either end and one intermediate main working shaft 299 feet deep: three ventilating shafts of depths from 100 to 250 feet were also projected, but one of them was abandoned while still incomplete owing to excessive water difficulties which were encountered: until the other ventilating shafts were sunk the work in the south heading, i. e., from the downstream end of tunnel, was much hampered by bad ventilation.

37. When work was first started electric air-drills were used, the electricity being supplied from a hydro-electric installation on the Swat River at the canal head, and the drills being driven by small motor compressors at the drill head the air rapidly became very foul.

In order to improve ventilation compressed-air drills were substituted, working from main stations outside the tunnel, and the cool air after release from the drill materially improved the ventilation within the tunnel. Although the electric drills were more economical of power than the compressed-air drills the work was done much more rapidly by the latter, owing partly to the improved atmospheric conditions for the operators induced, and partly owing to the air drills being much more handy to move than the others.

38. The total estimated cost of the tunnel was Rs. 1,650,000, including the power installation and plant; the actual cost of the excavation exclusive of those items was:

Drilling	1.73 annas per cubic foot.
Blasting	2.53 " " " "
Disposal of soil	1.07 " " " "
	5.33

The share of fixed charges for power plant estimate brought up the total cost to about 6.25 annas per cubic foot.

N. B.—An anna is nearly equal to 2 cents American.

Hydro-electric Installation for Combined Drainage and Irrigation, Bari Doab Canal.

39. This work which is now under construction may be referred to as the first serious attempt in this country to correct by pumping an undesirably high spring level in the soil due to excessive irrigation.

Plate IV shews the general scope of the scheme. The tract under treatment is in the immediate vicinity of the City of Amritsar, where, owing to the comparatively high value of the crops raised, cultivation is intense, with irrigation from the distributary of the Bari Doab Canal shewn on the plan; consequently the subsoil water has gradually risen to within a few feet of the ground surface. Owing to the general low level of the tract as compared with the only available natural drainage outfall, it is not possible to attempt to lower the subsoil water-level by open or piped gravity drains, and the present scheme for reduction of the subsoil water-level by pumping is experimental in its present stage. Ample water power was available in the Main Bari Doab Canal where a masonry fall already exists at the site shewn on the plan. The supply and fall sufficed for 3 turbines each of 270 hp., operating three-phase alternators each of 175 kilowatts.

40. The power transmission line of 6000 volts is shewn on the plan; also the location of the 10 pumping stations now being installed, which have been chosen so as to conveniently discharge into the existing irrigation channels. By this arrangement existing irrigation rights will not be interfered with; the only difference being that the supply instead of being derived, as heretofore, from the Bari Doab Canal, thereby aggravating the high spring level, will be pumped from the subsoil water, thereby reducing it.

41. As the subsoil is of very fine sand the supply will be obtained from tube wells sunk from 100 to 120 feet from ground surface. The tubes of 10″ diameter are constructed of special copper wire of triangular section wound closely round a skeleton frame-work of steel rings and bars. The pumps are centrifugal, working on a vertical spindle at the bottom of the supply pipe, which, with the pump, is lowered into the well tube after that has been sunk; and each pump is to be worked by a

12 hp. three-phase motor. Experiments carried out during the past 3 years shew that such a pump and tube well will yield a continuous supply of 2 cubic feet per second without clogging the tube well by drawing in the sand.

42. The preliminary stage of the scheme which is now under construction does not require the whole of the power available, and some of the power is to be used for manufacturing purposes; but if the pumping scheme proves successful in materially reducing the spring level, it is to be extended up to the limit of the water power available.

The scheme is a novel one certainly in India, and I much regret that at the time of writing I am unable to deal with results, which are awaited with much interest. It is expected that pumping will be commenced early in 1916.

TABLE I.

Statement Showing Total Area Irrigated under Several Heads.

Year	I Productive	II Protective	III Minor works for which capital and revenue accounts are kept (including works under construction)	IV Minor works for which only revenue accounts are kept	V Works for which neither capital nor revenue accounts are kept	Total for the year
	Acres	Acres	Acres	Acres	Acres	Acres
1902-03	12,222,690	369,805	2,256,177	1,846,330	3,476,076	19,801,273
1903-04	12,989,801	383,990	2,187,292	2,293,991	3,651,596	21,506,670
1904-05	12,616,767	433,823	1,976,978	2,075,135	3,004,807	20,107,510
1905-06	14,692,450	469,990	2,139,154	2,317,051	3,369,418	22,988,063
1906-07	13,884,281	212,274	2,248,399	2,347,727	3,532,268	22,224,949
1907-08	14,518,320	355,709	1,790,657	1,925,764	3,357,981	21,948,431
1908-09	14,623,991	352,103	1,967,464	2,416,588	3,403,231	22,760,377
1909-10	14,284,270	306,057	1,879,791	2,500,485	3,445,145	22,415,748
1910-11	14,175,414	284,212	1,905,893	2,563,631	3,589,940	22,519,090
1911-12	15,579,574	325,378	1,816,309	2,315,602	3,250,191	23,287,054
1912-13	16,147,799	403,200	2,001,952	2,540,317	3,421,917	24,515,185
1913-14	16,650,029	552,438	1,992,449	2,513,829	3,275,231	24,983,976

TABLE II.

Statement Giving Particulars of Some of the Larger Productive Works in Operation.

Province	Name of Work	Capital cost on March 31, 1914	Net revenue realised in 1913-1914	Percentage of net revenue to capital cost	Area irrigated	Mileage of Main Line	Mileage of Distributaries
		Rs.	Rs.		Acres	Miles	Miles
Madras	Cauvery Delta system	4,132,355	832,881	20.15	212,651	1,507	1,971
	Godavari Delta system	14,615,472	3,031,792	20.74	839,148	502	2,001
	Kistna Delta system	16,080,383	2,838,523	17.65	664,334	349	2,182
	Kurnool Cuddapah canal	22,654,984	162,731	.72	77,432	407	286
	Periyar system	10,570,165	404,168	3.82	90,891	103	106
Bombay (Sind)	Jamrao canal	8,408,780	466,267	5.55	232,790	180	457
United Provinces	Upper Ganges canal	36,598,007	3,562,014	9.73	1,179,407	567	3,247
	Lower Ganges canal	41,681,687	2,339,882	5.61	1,199,918	662	3,133
	Eastern Jumna canal	5,158,198	1,355,548	26.28	355,437	129	799
Punjab	Western Jumna canal	17,604,110	2,169,667	12.35	779,139	294	1,537
	Upper Bari Doab canal	21,442,471	3,356,457	15.65	1,120,137	325	1,609
	Sirhind canal	25,398,523	2,877,931	11.33	892,869	319	1,751
	Lower Chenab canal	31,193,489	13,149,451	42.15	2,245,598	427	2,278
	Lower Jhelum canal	15,966,086	3,324,255	20.82	823,532	150	1,046
Burma	Shwebo canal	5,854,057	511,851	8.76	170,850	76	284
Bihar and Orissa	Orissa Project	26,974,242	—21,834	—.08	279,095	327	1,279
	Sone Project	26,844,935	1,171,098	4.36	530,438	368	1,234

Note.—A Rupee is nearly equal to one-third of an American Dollar and 15 Rupees are equal to one Pound sterling.

TABLE III.

Province	Net area cropped	Area irrigated by government irrigation works	Percentage of irrigated area to total cropped area	Capital cost of government irrigation works to end of 1912-13 in lakhs of rupees	Estimated value of crops raised on areas receiving state irrigation, in lakhs of rupees
	Acres	Acres	Per cent		
Burma	13,856,000	1,275,000	9.2	205	524
Bengal	25,955,000	108,000	0.4	227	59
Bihar and Orissa	8,006,000	971,000	12.1	662	347
United Provinces of Agra and Oudh	35,460,000	2,698,000	7.6	1,184	1,438
Ajmer-Merwara	356,000	24,000	6.8	35	11
Punjab	22,684,000	8,368,000	34.6	1,625	3,071
North-West Frontier	2,549,000	246,000	9.6	63	84
Sind	3,991,000	3,065,000	76.8	316	821
Bombay Deccan	22,906,000	355,000	1.5	438	123
Central Provinces (excluding Berar)	17,969,000	78,000	0.2	88	14
Madras	39,120,000	7,321,000	18.7	1,081	1,831
Baluchistan	Not known	6,000	....	32	2
Total	192,852,000	24,515,000	12.4	5,056	8,325

Note.—A lakh is 100,000.

TABLE IV.

Province	Name and class of work		Total direct cost to end of 1912-13 Rs.	Irrigable area Acres	Principal crops that can be produced
Bombay	Kadwa river works	Productive	971,741	32,723	Wheat, sugar cane and ground nuts.
	Chankapur tank project	Protective	1,671,077	15,000	Wheat and gram.
	Pathri tank project	Minor	627,825	2,500	Millets.
	4th small tank projects	Minor	865,416	6,325	Wheat, rice and gram.
Sind	Jamrao canal	Productive	8,147,933	300,000	Cotton, millets and wheat.
	Nasrat canal	Productive	1,830,064	104,100	Cotton, millets and oil seeds.
	Dad canal	Productive	2,420,982	145,400	Cotton, millets and oil seeds.
	2 small canals	Minor	463,957	53,757	Rice and millets.
Bengal	Dhaka canal	Protective	554,835	6,387	Rice.
United Provinces	Ken canal	Protective	4,977,584	120,000	Rice, wheat and gram.
	Dhasan canal	Protective	4,412,347	57,000	Wheat and gram.
	Pahuj and Garhmau canals	Protective	794,401	17,200	Wheat, gram and rice.
Burma	Mandalay canal	Productive	5,216,006	59,115	Rice.
	Shwebo canal	Productive	5,725,024	151,734	Rice.
Central Provinces	12 small tank projects	Protective	2,148,236	34,634	Rice.
North-West Frontier Province	Paharpur canal	Productive	905,444	41,588	Wheat and millets.
	Total		41,732,872	1,147,463	

TABLE V.

Results of Irrigation Works in Operation in India.

Class of work	Capital outlay to end of the year on works in operation	Gross revenue during the year	Net revenue during the year	Percentage of net revenue of capital outlay to end of year	Net profit during the year; *i. e.*, net revenue less interest charges	Area irrigated
	Rs.	Rs.	Rs.	Per cent	Rs.	Acres
I.—Productive	470,347,274	64,353,975	44,833,565	9.53	29,685,579	16,147,799
II.—Protective	60,436,601	1,243,758	450,302	0.75	—1,509,876	403,200
III.—Minor works for which capital and revenue accounts are kept (including works under construction)	64,829,224	5,263,049	2,849,392	4.39	....	2,001,952
IV.—Minor works for which only revenue accounts are kept	....	6,801,346	3,489,458	......	....	2,540,317
V.—Works for which neither capital nor revenue accounts are kept	....	10,681,405	6,075,315	......	....	3,421,917
Total 1912-13	595,613,099	88,343,533	57,698,032	(a)8.08	....	24,515,185

Province	Name and class of work		Estimated cost, direct and indirect Rs.	Expenditure to end of the year 1912-13, direct and indirect Rs.	Irrigable area in acres
Punjab	*Lower Jhelum canal	Productive	18,963,988	15,965,622	766,182
	*Upper Chenab canal	Productive	37,357,024	29,531,355	648,368
	Upper Jhelum canal	Productive	43,996,559	31,397,898	344,960
	*Lower Bari Doab canal	Productive	22,328,402	16,613,251	877,908
N.-W. F. Province	Upper Swat River canal	Productive	19,924,287	11,660,901	381,562
United Provinces	Permanent Head Works, Upper Ganges canal	Productive	3,378,324	....	86,166
	Ghaggar canal	Protective	3,504,454	261,946	66,000
Central Provinces	Weinganga canal	Productive	3,803,204	462,296	78,965
	Mahanadi canal	Productive	9,930,217	709,237	360,000
	Tandula canal	Protective	9,998,807	2,282,040	263,412
	Chorkhamara tank project	Protective	865,484	19,832	20,000
	Badalkhassa tank project	Protective	657,288	8,391	18,376
	Naleshwar tank project	Protective	632,542	75,443	12,000
	*Asola Mendha canal	Productive	1,797,578	1,351,010	60,000
	*Ramtek reservoir	Protective	2,907,858	2,842,665	48,000
Madras	Mopad reservoir	Protective	2,151,000	623,670	12,500
	*Divi pumping scheme	Productive	1,998,000	1,864,495	50,000
	*Nagavalli reservoir	Productive	1,816,300	1,572,156	23,814
Bombay Deccan	Nira Right Bank canal	Protective	25,772,499	606,480	231,000
	*Pravara River canal	Protective	7,610,826	2,721,520	60,379
	*Godaveri canal	Protective	9,561,044	8,504,751	175,600
	Budhihal tank	Protective	1,454,611	508,274	6,226
Bombay (Sind)	*Mahiwah canal	Productive	1,517,356	1,437,374	65,950
Bihar and Orissa	*Tribeni canal	Protective	7,527,302	6,809,779	106,000
Burma	*Mon canals	Productive	5,431,022	5,393,667	68,000
	Ye-u canal	Productive	5,054,752	1,667,651	108,294
	Twante canal	Productive	7,280,973	1,600,292	....
	Total		257,221,701	146,491,996	4,939,662

* In partial operation.

TABLE VII.
Projects Under Investigation.

Province	Name and probable classification of work		Estimated or approximate direct cost in lakhs of rupees	Irrigable area in acres	Districts benefited	Principal crops that will be produced
Madras	Cauvery reservoir project	Productive	370	473,000	Tanjore.	Rice.
	Kistna reservoir project	Productive	800	735,000	Kistna and Cuntur.	Rice.
	Lower Bhavani	Productive	109	109,200	Coimbatore.	Rice.
	Velgode project	Productive	28	61,000	Kurnool.	Rice.
	12 smaller schemes	Mainly Protective	344	355,000	Ganjam, Nellore, Kurnool, Coimbatore, Anantapur and Salem.	Rice.
Bombay	Gokak canal extension project	Protective	183	132,000	Belgaum, Bijapur and the Native States of Kolhapur, Mudhol, Jamkhandi, Sangli and Kurandwad.	Wheat, bajri, juari and oil-seeds.
Sind	Rohri canal, Sukkur Barrage and widening Eastern Nara Supply channel	Protective	762	2,324,000	The whole Left Bank Division comprising three Revenue districts viz., Nawabshah, Hyderabad and Thar and Parkar.	Cotton, wheat and rice.
	Sultanwah, Begari canal	Productive	16	177,700	Sukkur and Upper Sind Frontier.	Rice, juari, bajri, wheat and oil-seeds.
Bengal	Damodar canal	Productive	36	150,000	Burdwan.	Rice.
Bihar and Orissa.	Extension of the Tribeni canal	Protective	10	25,000	Champaran.	Rice.
United Provinces	Belan canal	Protective	15	30,500	Kairagarh Pargana, Allahabad district.	Rice and wheat.
United Provinces and Punjab	Sarda-Ganges-Jumna feeders projects	Productive	646	1,524,000	In the United Provinces—Rampur State, Pilibhit, Shahjahanpur, Hardoi, Bareilly, Moradabad, Budaur, Saharanpur, Muzaffarnagar, Meerut, Bulandshahr, Aligarh, Muthra, Agra, Etah, Mainpuri, Farukhabad, Etawah, Cawnpore, Fatehpore and Allahabad. In the Punjab—Gurgaon, Karnal, Delhi, Rohtak, Hissar, Patiala and Jhind States.	All the principal rabi and kharif crops grown in the United Provinces.
Punjab	Sutlej Valley project	Productive	875	3,000,000	Lahore, Ferozepore, Montgomery, Multan, Bikaneer and Bahawalpur States.	Wheat, gram, jowar and cotton.
Burma	Remodelling the Kinda canal	Productive	15	85,000	Kyaukse.	Rice.
Central Provinces.	Pangoli Nalla tank project	Protective	16	33,000	Bhandara.	Rice.
	Deena Nadi tank project	Protective	14 to 25	45,260	Chanda.	Rice.
Baluchistan	Anamber reservoir project	Productive	38	80,000	Loralai.	Wheat and barley.
	Torwal reservoir project	Productive	18	44,000	Loralai.	Wheat and barley.
	Gamboli reservoir project	Productive	60	218,000	Sibi.	Wheat and barley.
	Zhob project	Productive	65	202,000	Zhob.	Wheat and barley.

Paper No. 43

THE DISTRIBUTION OF WATER IN IRRIGATION IN AUSTRALIA.

By

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INTRODUCTION.

The purpose of this paper is to describe the methods employed and the results obtained in distributing water for irrigation in Australia. It is believed that in no other part of the world has water greater value or its conservation and economical distribution greater economic importance. This grows out of the low and very irregular rainfall of the Continent. The normal years are periods of unusual prosperity, but these are interspersed with years of disastrous floods or of devastating drought. In more than half of the Continent the average annual rainfall is less than ten inches and there are places where no rain has fallen in drought years.

It is, on the other hand, a country of moderate and comparatively even temperatures. In Melbourne the mean temperature for January, the hottest month, is 66° and for July, the coldest month, 47.6°; while the extremes of heat and cold in the year are 111° and 27°. Such a climate is well suited to the growing of stock, and the rapid development of the live-stock industry in Australia has been aided by the nutritious natural grasses which grow everywhere except in the deserts. Millions of cattle and sheep range over the vast interior and are brought to maturity without having been housed or fed a single day.

The profits of stock raising in normal years are large. The wool of Australia commands the highest prices in the world's

markets; its horses are in great demand as re-mounts for the British army; and there is a ready sale for more mutton and beef than can be produced. There are, however, years in which rain does not fall, when the grass withers and millions of acres of pasture land are bare of vegetation. Then fodder to keep stock alive must be found and bought almost regardless of price. Unless this can be done, the losses of starving stock are sudden and ruinous. In the year 1902 it is estimated that 1,428,686 cattle and 18,371,864 sheep died of starvation; and with increasing population and settlement, these losses will be augmented, unless through irrigation fodder for such seasons can be produced.

Importance of Irrigation in Growing Fodder Crops.

Owing to the long growing season and mild climate, irrigated alfalfa can be cut from 5 to 7 times a year, and where water for irrigation is available, large yields are secured. As the Continent of Australia is about the size of the United States and the irrigated area, present and prospective, is considerably less than that now irrigated in the State of California, the demand in drought years for the hay and pastures of the irrigation districts gives rise to prices practically unknown elsewhere. At the time this paper is written, alfalfa hay sells in Victoria for from $50 to $80 a ton, and promises to reach higher prices. During four of the last seven years, it has reached prices varying from $30 to $40 a ton. During the present season, $100 an acre has been paid for the rent of green alfalfa fields for about four months; $2 a week has been paid for the pasturage of horses, and as several can be kept on an acre, it means that on a few irrigated farms pasturage fees alone will, this season, more than pay for the land. In time, such returns will give to irrigated land very high values and warrant large expenditures for conserving water. Alfalfa land now sells for from $300 to $500 an acre in the Valley of the Hunter River in New South Wales and along Werribee River in Victoria.

Irrigation in Fruit Growing.

Fruit growing on the irrigated areas is also highly profitable, and, with improvements in export transportation, promises to be still more so in the future. There is a local demand for all the citrus fruit grown, and this demand is expanding almost as

rapidly as production. The tariff has made the growing of dried fruit, like raisins and currants, profitable, but the great field for expansion in the fruit industry is through the export of fresh fruit to the world's centres of population. Owing to Australia being in the Southern Hemisphere, it is enabled to land fresh peaches and grapes in the markets of Europe and America in mid-winter, when there is no local competition. Already, a large export trade in apples and pears with European countries has been established, and this promises to be followed by an equal development in the shipment of more perishable fruits, like peaches, plums and grapes. Irrigation in Australia is destined to be, therefore, largely devoted to the production of fruit and fodder crops.

IRRIGATION IN AUSTRALIA LARGELY CONFINED TO THE MURRAY RIVER AND ITS TRIBUTARIES.

It has already been explained that the rainfall of Australia is small and irregular. There are no mountains where snow remains throughout the year, while, on the other hand, the sudden and heavy monsoonal rains make conservation in Northern Australia costly and hazardous. Brisbane River, in Queensland, has risen 30 feet in 24 hours. Hawksbury River, in New South Wales, has risen 62 feet above the mean. Reservoirs to store such floods can not be attempted while land is cheap and population too small, and little can be accomplished with the meagre flow of these rivers in the dry months. The chief exception to this is the Murray River, which rises in the high lands that parallel the eastern and southeastern coasts of the Continent. From this source, it flows westward between the States of Victoria and New South Wales, of which it is the boundary, through a wide, gently sloping plain, and then crosses South Australia, on the way to the Southern Ocean.

The whole flow of the river comes from Queensland, Victoria and New South Wales. No tributaries join it in South Australia. For a period of 10 years—1895 to 1905—the average yearly discharge, measured near the boundary of South Australia, was 5,043,000 acre-feet. There were no flood years in this cycle; on the other hand, in a longer period—viz., the twenty-one years, 1890 to 1911, which included the greatest recorded flood—

the average yearly discharge was 8,318,000 acre-feet. In this period the discharge for the highest year was 17,093,000 acre-feet; the lowest 1,687,000 acre-feet. That is, in the year of lowest flow the discharge was less than one tenth that of the highest.

Present Irrigation Development in the Murray Valley.

Each of the three States diverting water from the Murray has its own water laws and each exercises independent control over the water within its boundaries. The laws of all three States make the water of natural streams the property of the Crown; and in all the States the larger irrigation works are owned and operated by the State authorities. The records of 1914 showed the following areas under irrigation or capable of being irrigated from works either completed or nearing completion.

Name of State	Area irrigated in 1914 acres	Additional area to be irrigated from works under construction in 1914. (estimated) acres	Total acres
New South Wales	50,000	225,000	275,000
Victoria	315,000	70,000	385,000
South Australia	25,000	22,000	47,000

DISTRIBUTION OF WATER IN THE STATE OF VICTORIA.

From the above table it will be seen that Victoria has more acres of irrigated land than all the other Australian States combined. Its methods of distributing water in irrigation will, therefore, be first described.

Victorian State Works for Providing Rural Water Supplies.

In order to understand the problems of distribution in Victoria, it is necessary to have a brief description of the State's topography and climate. The map attached to this paper also shows the location of the principal irrigated areas. (See Plate I.)

The southern boundary of the State of Victoria is the ocean. The northern boundary is the Murray River. About midway between these a dividing range of mountains crosses the State from east to west. On the southern slopes of this dividing range the rainfall is generally ample for the production of crops.

It is the humid half of the State, having a rainfall varying from twenty to fifty inches per year. North of the dividing range the climate is arid or semi-arid, the mountains acting as a barrier to the clouds coming inland from the Southern Ocean. In the semi-arid part of the State, the heaviest rainfall is in the eastern half, where it varies from fifteen to twenty inches. It progressively diminishes westward until at the western boundary it is only about ten inches. From about the middle of this semi-arid strip to the eastern end, all of the streams are perennial: The Goulburn River being the most important water supply and the principal tributary of the Murray. In the western half none of the streams reach the Murray and in summer most of them cease to flow. Here over a great extent of fertile land there are neither surface water supplies nor underground water suitable for household uses. The rainfall, however, is sufficient to grow good crops of grain and to afford excellent pasturage for horses, cattle and sheep. Grain growing and stock raising have proven so profitable that this has become an important granary of the State.

Water Supplies for Household and Stock Purposes.

Its settlement and occupation were, however, dependent upon a water supply being provided for household and stock purposes and this has to be brought to each farm by artificial means. Large storages have been built along the northern slopes of the dividing range and diversion weirs constructed in a number of the principal streams near the foot of this range. From these weirs small surface ditches have been built, in some cases a distance of two hundred miles, that run quite largely in parallel lines following the slope of the country from south to north. On each farm tanks have been made by throwing dams across depressions or excavating basins capable of holding from five hundred to five thousand cubic yards of water. The State builds and operates the main supply channels, the individuals build the tanks and maintain the channels which run from the main supply to these tanks. The aim of the Government is to fill these tanks once a year operating the main supply channels only in the winter and spring months, as the great loss from seepage and evaporation during the hot summer season makes continuous operation impracticable. It frequently happens, however, that

through neglect to build channels of sufficient size or increased demands on these tanks during especially dry years, that the channels have to be operated in summer.

While the main purpose of these channels is to provide water for household and stock purposes, limited irrigation is possible and is being extended. In three or four localities a few hundred acres have been planted to orchards which are irrigated and on many farms windmills are installed and water pumped from the tanks to irrigate an acre or two around the house. This makes possible the growing of trees for shade and shelter, the creation of lawns and the production of fruits and vegetables for the farmer's family. These green oases in what is otherwise a dusty brown landscape make the appearance of the country and the conditions of life much more attractive than they would otherwise be. The cost of supplying the additional water needed for the irrigation of these small areas is but little more than that spent in operating the system to supply water for domestic and stock purposes only. The Government is, therefore, encouraging the extension of this kind of irrigation.

The money required to pay interest on the cost of these works and to operate and keep them in repair is obtained from a rate fixed each year by the Water Commission. This rate is levied on all the land benefited but is not uniform. Lands directly connected with the channels pay the highest rate; lands within one mile of the channels, an intermediate rate, and lands more than one mile and less than three miles, pay a still lower rate. The amount also varies in the different districts depending upon the cost of the work, expenses and difficulties of operation.

Works for Irrigation.

In the eastern half of the semi-arid section of the State the greater part of the water supply is used for irrigation, but there are districts in which the works partake of the character of both the dryer and more humid sections, that is, comparatively small channels supply large areas in which only a fraction of the land is intended to be irrigated. On the remainder, water is supplied only for stock and domestic uses. A water supply system of this character has been evolved because most of the land is held in large holdings and the owners prefer to continue

a combination of grain growing, without irrigation, on large areas, with intensive cultivation of small irrigated areas. Owing to the great length of channels and excessive loss of water, operating charges compared to the acres actually irrigated, are very high. If the whole expense had to be paid by the irrigated acreage, the cost would be prohibitive. This is averted by imposing a double charge in these districts to conform to the dual services rendered. One charge is made for the water supplied for irrigation, the other is a charge made for providing water for stock and domestic purposes on the unirrigated portion of the area. This, as in districts where little or no irrigation exists is made a rate based on the value of the land. The amount of the two sources of revenue is intended to produce an income which will give four per cent on the cost of the works and meet all expenses of operation and maintenance.

No State works to supply water for domestic and stock purposes are required in the more humid country south of the dividing range, but works to supply water for irrigation have been completed in two districts along the Werribee River.

The total expenditure of the State on works for rural water supplies has been £7,750,000. Of this £2,792,383 has been spent on works for irrigation alone.

The Evolution of the Present Victorian Irrigation System.

The Victorian irrigation system and the laws which control its operation are an evolution. In their final form the results will compare favorably with those obtained in any other country. During the period of twenty-five years there has never been a water-right law suit in the State, and controversies over water ownership are practically unknown. This result is, in a large measure, due to the wisdom and foresight of the early water-right legislation, which made all public water supplies the property of the State. In order that the State might make its declaration of public ownership of water effective, it retained in perpetual State ownership the land forming the bed of streams and a margin on each bank from one to three chains wide. This makes the State the sole riparian proprietor. Wherever private diversions have been made they are under a permit which gives authority to occupy the State land and divert a designated quantity of water. None of these rights are perpetual; most of

them are under an annual permit which has to be renewed each year, but a few are under license which extend up to fifteen years. There are at present about twelve hundred diversions under licenses and permits. The largest of these irrigates about twelve thousand acres and altogether they irrigate about forty thousand acres of the three hundred and fifteen thousand acres irrigated in 1914.

Prior to 1906 nearly all irrigation works were controlled by local bodies. The larger ones supplied water to areas of land that had been organized as irrigation districts under a law modeled on the Wright Act of California, and having many of its features. The money for construction was, however, all supplied by the Government, which loaned it to the districts and the works were built under the oversight and supervision of Government engineers. The results of this plan were not satisfactory. The local land owners had no investment in the works and as they fixed the price of water and enforced collection of revenue needed to repay the Government loan and interest thereon, there was a strong temptation to consider the interests of the land owners rather than the Government. In none of the districts was there a compulsory charge for water. In each case land owners only paid for the water they used and if they used none, they paid nothing. The only certain revenue was the rate imposed for water supplied for domestic and stock purposes. All of these districts fell into arrears and in many of them the works themselves were allowed to fall into bad repair. When it became manifest that a continuance of this system would mean a loss of all or a large part of the State's investment, the State, in 1906, passed an Act abolishing the local district organizations and took over the ownership and management of all the works, assuming in doing this all of the district's liabilities. The State under this Act came into possession of twelve large districts, and a number of smaller ones, widely separated and varying widely in the manner in which the works had been kept in repair.

The operation of these works was entrusted to a board of three, created by the Water Act of 1906, called the State Rivers and Water Supply Commission. At the outset the duties of this Commission were restricted to operating the existing works and recommending the construction of new ones, which were to be

built by the engineers of the Water Supply Department. This was changed soon after by abolishing the Water Supply Department and giving the Commission control of construction. At a subsequent date the added responsibility and duty of acquiring, developing and settling much of the land irrigated was entrusted to the Commission.

Operation of State Irrigation Works by the Commission.

Prior to the Commission taking control of these works the water supply for irrigation had been paid for by a charge on the acres irrigated. No measurements were made of the volume used nor special efforts to induce economy in use. Water was supplied in the order requested by irrigators, but was not supplied at any regular intervals and in many cases there was great delay in delivery. In cool weather irrigators postponed giving orders as long as possible and when the hot days came all rushed in and ordered at once. In such cases it was often from three to six weeks before these orders could be filled. This was unsatisfactory to both the Commission and the irrigator and one of the first actions of the Commission was to introduce a system of rotation in water deliveries.

Under the original plan of charging by the acres watered, irrigators were inclined to use all the water they could force into the soil. In many cases this injured both crop and land and was a great source of waste of water. This was ended by basing the charge on the volume of water supplied which promoted economy because the buyer who used water economically got the full benefit of his saving in a smaller water bill. Fixing definite periods for the delivery of water encouraged the irrigator to prepare his fields in advance and thus utilize all the water turned into the head of the distributary channels.

Experiments in Water Measurement.

The change in the law requiring water to be sold by measurement made it incumbent on the Commission to find some device suited to local conditions which would give at least an approximate record of the quantity delivered. This was not an easy task, owing to the slight fall in most of the irrigation districts. The main channels which carry water from the Goulburn River to the districts which it waters have a grade of only three inches to the mile and the surface of much of the land to be irri-

gated is within four inches of the water surface in the canals when they are full. Any meter or device adopted must, therefore, operate with very slight loss of head.

The Grant-Michell Meter.

Irrigators were practically unanimous that the device for measuring water should be self-recording and one in which the accuracy of the record would not be affected by changes in the water level of the canals. The first meter tested was the Grant-Michell, named after its inventors, two Australian engineers.

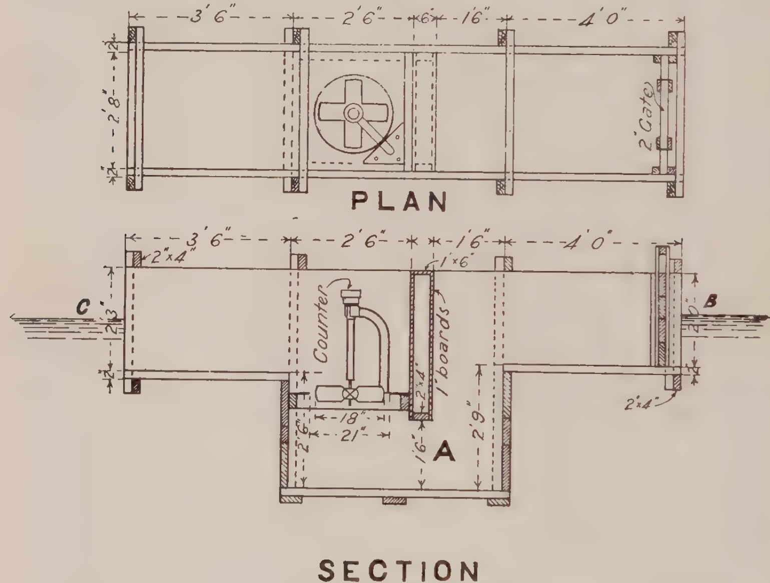


Fig. 1. Grant-Michell Meter.

Its forms and methods of installation are shown in Figures 1 and 1a.

It consists of a wheel turning in a horizontal circular opening through which the water is made to pass. This opening is a little below the bottom of the ditch. The direction of the water in passing through the box is shown by the arrows in the illustration. After dropping into the well below the ditch bottom, it passes under the diaphragm and rises through the circular opening in which the meter is set and then passes on to the ditch. The meter consists of four flat blades, so set that the water in

flowing through the circular opening strikes against them at an angle. In this way the wheel is turned by the current, like a windmill in a breeze. On the upper end of the shaft carrying the wheel is a counter, which records the number of revolutions of the wheel. This meter is made in 4 sizes: 12-inch, 18-inch, 21-inch and 39-inch. The rated capacities for these sizes, given by the makers, are 1.66, 3.75, 5.83 and 16.66 cubic feet per second, respectively. The wheel, counter, and standard for holding the wheel are sold and controlled by the patentees or their licensed agents. The prices quoted for Pacific Coast delivery,

Fig. 1a. Four Grant-Michell Meters in Operation.

in lots of not less than 6, with freight, but not duty, paid, are \$52.25, \$66.75, \$74.20, and \$170.30, respectively, for the four sizes. The box for the meter can be built of either wood or concrete. The standard for holding the meter is arranged so that the meter can be removed when not in use. On systems where the flow through each meter is not continuous, the meter can be used on more than one outlet, being moved around as water is turned out.

Tests made with the 18″ meter show that it will give a discharge of 1 cusec and record within 3% of the true quantity with a fall of between 3 and 4 inches. These tests have been con-

firmed by those made by the Experimental Station of the University of California.* (See Fig. 16.) The meter has two faults. The first is its cost. With the box, the average cost in place of these meters, in Australia, is about $100; the second, is the ease with which it can be interfered with. A resourceful irrigator, by dropping a stick or passing a plank two feet long into the current, can effectively stop the wheel and the record of discharge without materially reducing the flow of water. And the number of such sticks which found their way into meters materially reduced the revenue of the Commission. Pieces of wire inserted through cracks in the covering of the box were equally effective; the dif-

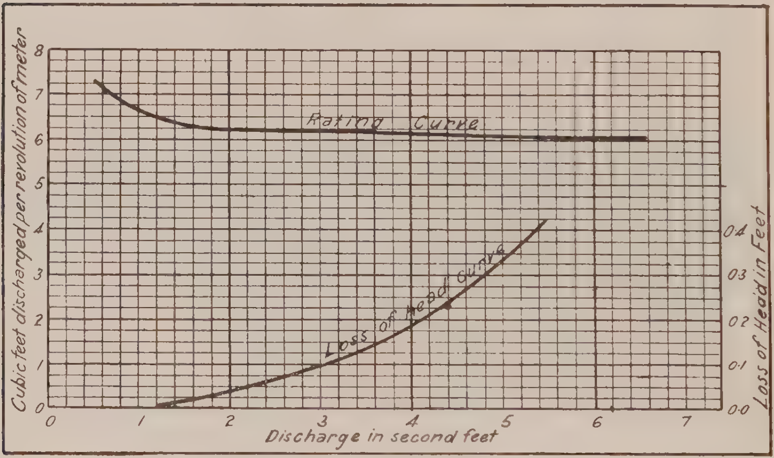
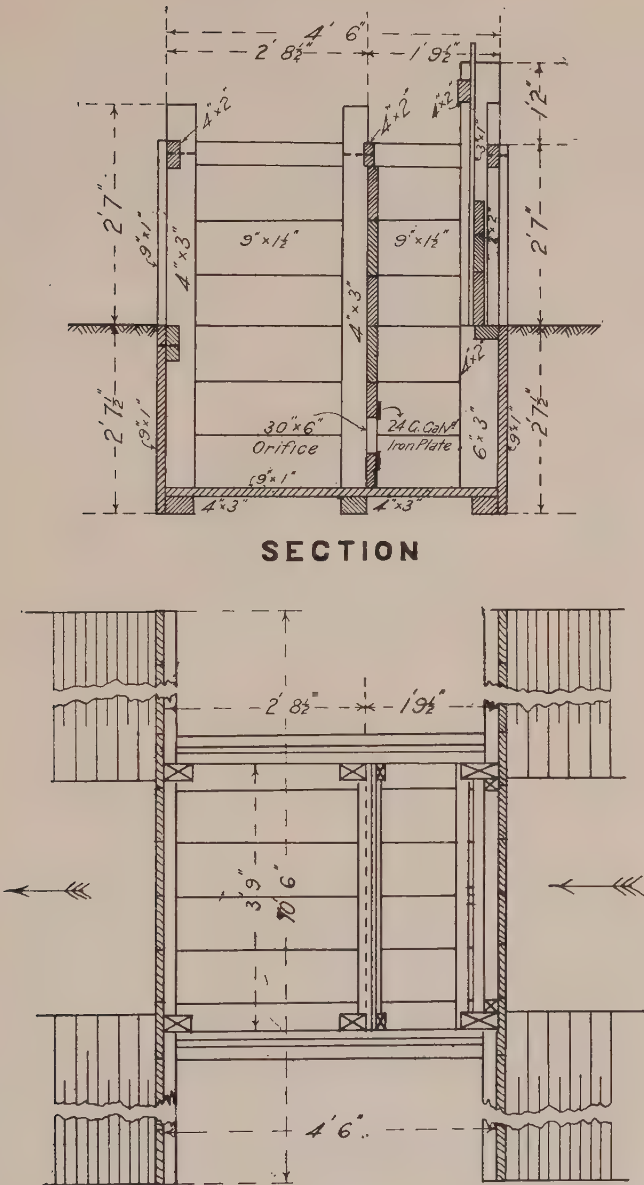


Fig. 1b. Rating Curve for Grant-Michell Meter.

ficulty of detecting these interferences and their continued recurrence became a serious objection to its adoption.

Measurement Through Submerged Orifices. After it was decided not to install any more of the Grant-Michell meters, the Commission was in a quandary; and in the absence of any satisfactory mechanical device, it converted the boxes in which the Grant-Michell meters were being installed into submerged orifices, by placing a metal plate in the opening, A, below the dia-

* "Some Measuring Devices Used in the Delivery of Irrigation Water", Bull. No. 247, College of Agriculture, Agricultural Experiment Station, Berkeley, Calif., U. S. A.—Editor.



PLAN

Fig. 2. Orifice Outlet.

phragm, Figure 1. This made it, in its operation, similar to the orifice of the Soldati meter, long in use in Italy.

The computed discharges for differences in the water level at B and C, Figure 1, were verified by two series of actual measurements, after which the following table of discharges was published for the information of irrigators and the use of water bailiffs. Figs. 2 and 2a shew an orifice outlet and its rating curve.

DISCHARGE FROM IRRIGATION OUTLET BOXES IN CUSECS.
SIZE OF ORIFICE IN INCHES.

Heads in inches	18″ x 6″	30″ x 6″	30″ x 8″
½	7	1.0	1.2
1	1.0	1.5	1.8
1½	1.3	1.8	2.3
2	1.6	2.2	2.8
2½	1.8	2.5	3.1
3	2.0	2.7	3.5
3½	2.1	3.0	3.8
4	2.3	3.2	4.1
4½	2.5	3.4	4.4
5	2.6	3.6	4.7
5½	2.7	3.7	4.9
6	2.9	3.9	5.2
6½	3.0	4.1	5.4
7	3.1	4.2	5.6
7½	3.2	4.4	5.8
8	3.3	4.6	6.0
8½	3.4	4.7	6.2
9	3.5	4.9	6.4

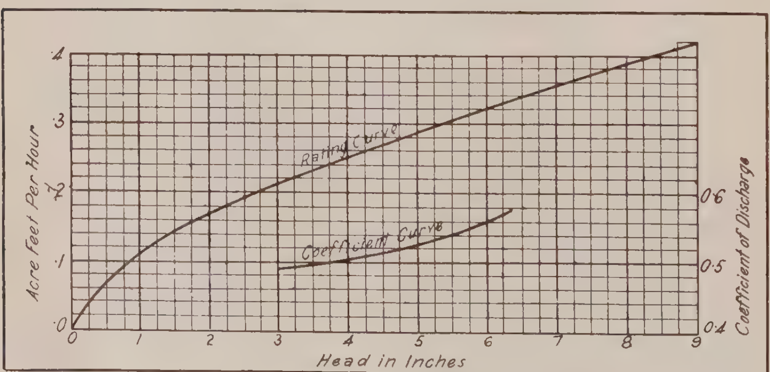


Fig. 2a. Rating Curve for Orifice Outlet.

These boxes are made of wood. About 3000 are in use in Victoria. The differences in level at B and C are read twice daily, and the mean of the two readings is used in determining the daily delivery.

Dethridge Meter. What the Commission regards as the solution of its problem of water measurements was found by Mr. J. S. Dethridge, M. Inst. C. E., one of its members.

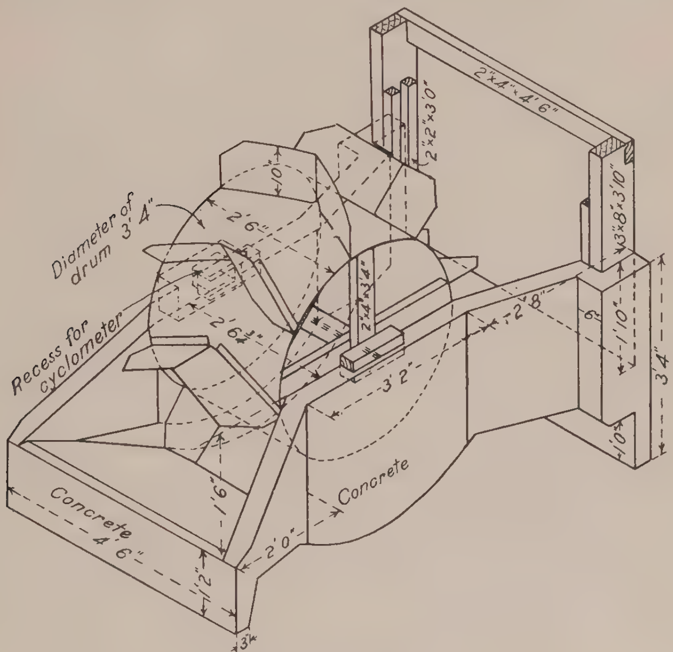


Fig. 3. Dethridge Meter.

The Dethridge meter is shewn in Figure 2. It consists of a rotor revolving in a fixed case. The rotor is a cylinder, open at the ends, to the external surface of which angular vanes are riveted. Both cylinder and vanes are of 20-gauge sheet iron, coated with anti-corrosive preparation. The cylinder is mounted on three crosses of 4″ x 2″ hard wood, which are keyed to an axle of ordinary 1″ pipe turning on plain hard-wood bearings. The case for the rotor is of reinforced concrete 3″ thick, and may be either built in position or moulded in sections at a depot,

with the steel projecting at joining edges, and then set up and jointed in place by forming bosses of cement mortar over the interlacing reinforcement. A Veeder cyclometer, driven off one end of the axle by means of a loose link, and encased to protect it from spray, registers the water passed, to 0.01 of an acre-foot.

The principle of the meter is positive measurement. Were it possible to make the edges of the cylinder and the vanes close fitting to the case, the quantity of water passed per revolution

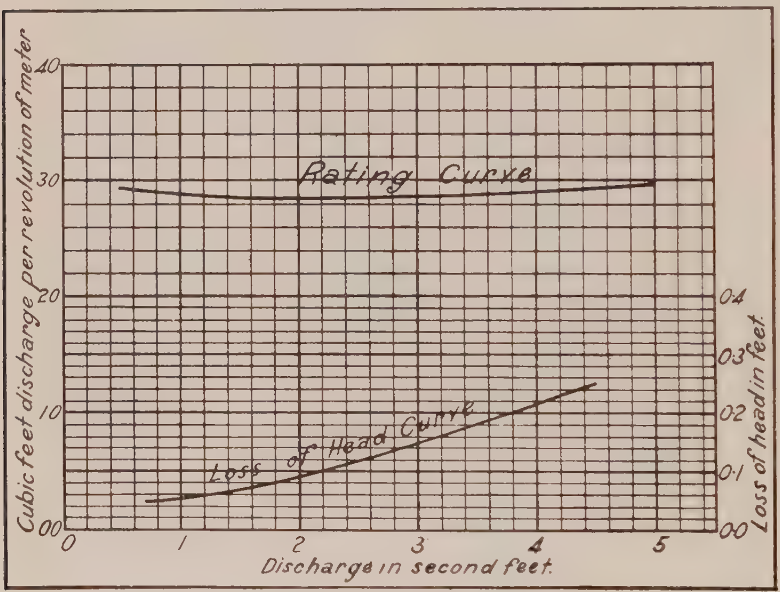


Fig. 3a. Rating Curve for Dethridge Meter.

would be the same in all conditions of action. But in ordinary field practice it is usual to allow a clearance of 3/8″ between the rotor and the case. The degree of accuracy attainable with this clearance is shewn by the rating curve accompanying the illustration of the meter. Fig. 3a shews the rating curve for one of these meters.

The standard size in general use in Victoria and New South Wales has a capacity of from ½ to 4½ cubic feet per second.

The merits of the device are delivery with small loss of head; accurate and continuous record; and freedom from risk of being

tampered with, because effective delivery ceases with stoppage of revolution. It is found that ordinary floating debris causes no trouble, the rotor having power enough to crush it. A gate in the case provides for shutting off or regulating the flow, the latter being an easy matter with the standard size, as the attendant has simply to allow one revolution per minute for each ½ sec.-foot. There is, also, provision for locking the rotor, but experience has shown that there is small need for this, the water left in the hollow of the case providing a sufficient anchor against revolution by wind action. The cost of the meter wheel in Australia is $10; the cyclometer, $1.25; and concrete case in place varies from $35 to $45; the average expense of the Dethridge meter, installed, in Victoria being about $50.

Water Right Allotments.

The Victorian water law requires the Commission to apportion each year to the irrigable land of each district a definite number of acre-feet of water, and fix the price per acre-foot, so that the sum obtained will pay 4 per cent interest on the district's debt and provide money for operation and maintenance. Each landowner has to pay for the water allotted his land as a right, if the State is prepared to supply it, whether he uses it or not. As only a small fraction of the land in each district was irrigated or in condition to be irrigated when the Commission took charge, the water right allotments were made smaller at the outset than will be required in the future. They are a compromise between what will ultimately be needed and what the existing landowners could use. The following table shows the allotments to the irrigable lands of the different Victorian districts taking water from the Murray and its tributaries.

Already two more closely settled districts are asking to have the water-right allotments increased to two acre-feet of water for each acre of land, and the records of water deliveries in 1914 showed that 29 acre-inches was the average quantity used in irrigating alfalfa, 16 acre-inches was the average for fruit and 11 acre-inches was the average for grain.

The Irrigation Seasons.

In dry seasons irrigation may be required every month of the year, but in normal seasons the rainfall of the winter months is sufficient. This has led to dividing the year into two seasons—

Name of District	Source of Supply	Water right per acre	Cost to irrigator per ac-ft.
Shepparton	Goulburn R.	1 ac-ft. of water for 1 ac. of land	$1.20
Rodney	Goulburn R.	1 ac-ft. of water for 4 acs. of land	1.20
Tongala	Goulburn R.	1 ac-ft. of water for 1 ac. of land	1.20
Rochester	Goulburn R.	1 ac-ft. of water for 1 ac. of land	1.20
Dingee	Goulburn R.	1 ac-ft. of water for 1 ac. of land	1.44
Tragowel	Goulburn R.	1 ac-ft. of water for 5 acs. of land	1.44
Deakin*	Goulburn R.		
Cohuna	Murray R.	1 ac-ft. of water for 1 ac. of land	1.20
Gannawarra	Murray R.	1 ac-ft. of water for 4 acs. of land	1.20
Swan Hill	Murray R.	1 ac-ft. of water for 1 ac. of land	1.20
Nyah	Murray R.	2½ ac-ft. of water for 1 ac. of land	3.36
Merbein	Murray R.	2½ ac-ft. of water for 1 ac. of land	3.60
Mildura†	Murray R.	2 ac-ft. of water for 1 ac. of land	

the regular, or summer irrigation season, and the winter season. In the summer irrigation season there is a compulsory irrigation charge for water allotted as a right. In the winter irrigation period there is no compulsory charge and only the water used has to be paid for. The regular summer season varies in the different districts; in the western districts, along the Murray, it begins with August and ends with April; in the middle districts it begins with September and ends with April; and in the eastern districts it begins with October and ends with April. In a majority of the districts the regular irrigation season is a period of 240 days, and arrangements have to be made for delivery of the water allotted as a right in uniform amounts at approximately uniform periods during this season. Irrigators are notified of the charge and conditions of delivery through a printed by-law, adopted each year. The following gives the essential paragraphs of one of these by-laws:

"STATE RIVERS AND WATER SUPPLY COMMISSION.

"BY-LAW No. 459.—IRRIGATION CHARGE.—RODNEY IRRIGATION AND WATER SUPPLY DISTRICT.

"The State Rivers and Water Supply Commission, in pursuance and exercise of the powers conferred by the Water Acts, doth hereby make the By-Law following:—

"1. The following Irrigation Charge is hereby made, and shall be levied upon the occupiers or owners of all lands to which Water

* In Deakin district there is no definite allotment as yet.

† Mildura is a municipally-owned district.

Rights have, under the provisions of the Water Acts, been apportioned by the Commission within the Rodney Irrigation and Water Supply District, which District is by notice given in the *Government Gazette* of 6th August, 1913, declared to be supplied with water for irrigation under the provisions of the said Acts:—

"For the supply of water for the irrigation of lands to which Water Rights have been apportioned as aforesaid, an Irrigation Charge of Five shillings for each and every acre foot of water apportioned to such lands as Water Rights.

"2. Such charge is made and shall be levied for the period beginning with the 1st day of October, 1914, and ending with the 30th day of April, 1915, and shall be payable on the 1st day of October, 1914, at the office of the Commission, at Tatura".

"STATE RIVERS AND WATER SUPPLY COMMISSION.

"BY-LAW NO. 359.—FOR THE SALE AND DISTRIBUTION OF WATER FOR IRRIGATION.—ROCHESTER IRRIGATION AND WATER SUPPLY DISTRICT.

"4. In the absence of any specific means of measurement, the quantity of water supplied shall be ascertained by accounting a watering as being a volume of water four inches in depth over any area watered, and for the purposes of this By-law and any By-law making an Irrigation Charge a watering shall mean the application of water to land for the purpose of irrigation, and a watering shall be and is hereby deemed to be a volume of water four inches in depth over any area watered.

"5. The charge for the supply of water for irrigation of lands to which Water Rights have been apportioned during the period from the 1st day of October in every year (beginning with the year 1913) to the 30th day of April in each succeeding year, shall be as set out in the By-law making the Irrigation Charge for such period; and if a supply is obtained in excess of any Water Rights apportioned to any lands during such period the charge for such excess shall be at the same rate of payment per unit of volume as that imposed in respect of the water apportioned to the lands as Rights.

"6. The charge for the supply of water for irrigation of lands other than those to which Water Rights have been apportioned during the period from the 1st day of October in every year (beginning with the year 1913) to the 30th day of April in each succeeding year shall be as agreed upon between the Commission and the persons requiring water.

"7. The charge for the supply of water for irrigation of all lands shall be:—

"During the period from the 1st day of May to the 31st day of May in every year (beginning with the year 1914)—Five shillings for each and every acre foot of water supplied.

"During the period from the 1st day of June to the 30th day of September in every year (beginning with the year 1914)—Two shillings for each and every acre foot of water supplied.

"8. An acre foot of water shall be and is for the purpose of this By-law and any By-law making an Irrigation Charge deemed to be such quantity of water as would cover an area of one acre to a depth of one foot.

"9. Applications for the supply of water for irrigation shall be made in writing to the Water Bailiff in charge of that portion of the district in which the land to be irrigated is situated, or to such other officer as may be authorized by the Commission to receive applications.

"10. Charges for water supplied for irrigation other than water supplied under a Water Right shall be payable at the office of the Commission, at Rochester, fourteen days after the date such water is supplied.

"11. Such person or persons as the Commission may from time to time appoint for that purpose shall be and is or are hereby authorized to demand, receive, collect, and recover the said charges.

"12. All persons taking water from the works of the Commission shall take delivery thereof through their respective outlets at such times, in such order, and in such manner as the Commission may direct.

"13. The outlets for the delivery of water shall be operated only by the Water Bailiffs of the district, or such other officers as may be authorized by the Commission".

There are few occasions in which water is delivered as a constant flow, the rule being to deliver in rotation periods. The length of these periods has been fixed by conference in the irrigation districts, and the two most commonly employed are for 15 and 22 days. In the 15-day rotation there are 16 waterings in the season and in the 22-day period there are 11 waterings. On most holdings about 4 cubic feet of water per second is regarded as a good working supply, but in orchards the tendency is to ask for smaller quantities and have the number of days in which water is supplied increased. On an 80-acre farm, with an 80-acre-foot water right and with a 15-day rotation period, the irrigator would be entitled to 5 acre-feet of water at each period, and if this were delivered with a stream of 4 cubic feet of water per second, the whole supply for one delivery would be received in 15 hours.

It often happens that irrigators require something more than their allotted quantity or do not desire to have any water delivered. In such cases irrigators are permitted to accumulate

two deliveries and have all the water delivered at once, or to obtain somewhat more than the allotment if notice that this is desired is given from 3 to 5 days in advance. Where notice that water is not desired is not given, the water has to be paid for, as it has been turned into the channels and is usually wasted.

In the orchard areas the deliveries are not uniform throughout the season. Most of the water is delivered in two main periods, extending through four months. The first period in most districts, comes in October and November, and the second in January and February. In the districts having a small water-right allotment, individual irrigators can contract, for a period of years, for an additional water right and pay for this exactly as though it were allotted.

Rotation Schedules.

Preparing the rotation schedules for districts like Rodney, in which 50,000 acre-feet of water is delivered in an area of 256,000 acres, is a complicated task. On some channels there are three sections, each under the control of a different water bailiff. The schedule has to fix for each day the number and location of outlets to be opened in each section and provide for water required in all three sections, with a proper allowance for loss by seepage and evaporation. The telephone is largely used in the operation of these sections, each bailiff notifying the man regulating the main channel two or three days in advance, so that the proper quantity can be turned into the distributary channels. The following insert (Fig. 4) is a copy of a Rotation Notice sent to irrigators at the beginning of each season.

Charges for Water and Costs to the State of Supplying It.

The present law has been in operation five years. Few changes have been made in the prices originally fixed for water supplied under the compulsory charge. All are very low. Nearly all are below the actual cost to the State, as the cost of fuel for pumping plants, cost of labor and of all material used in construction and repairs have advanced from 25% to 35%. The annual deficits have, however, been small, and as the use of water is increasing faster than working expenses or interest on the capital debt, increases in price have been delayed until the new settlers have their lands prepared for irrigation. Under

STATE RIVERS AND WATER SUPPLY COMMISSION.

Rodney Irrigation and Water Supply District.

SCHEDULE OF DELIVERIES OF WATER
(Subject to Rules and Regulations).

To Mr. ...., *Owner or Occupier of Allotment or part of*

Allotment No. .... *Parish of*

Sir,

There will be ten deliveries of water in the Rodney Irrigation District during the season of 1914-15. These deliveries will begin on the following dates:—

1st—October 1st.	2nd—October 22nd.	3rd—November 12th.
4th—December 3rd	5th—December 26th.	6th—January 16th.
7th—February 6th.	8th—February 27th.	9th—March 20th.
	10th—April 10th.	

Unless otherwise notified, your times for receiving water at these deliveries will be as follow:—

The duration of time during which your allotment of water will be supplied to you will be ....hours from and following the above-mentioned times of commencement.

The volume to which you are entitled at each delivery is .... acre feet

The distribution of water will be subject to the following conditions:—

The duration of each rotation period will be twenty-two days. Parties desiring extra water or desiring to omit irrigating at any one rotation period must give notice in writing five days in advance of the delivery date fixed in this notice.

Irrigators who have given notice that they will not use their allotment at one rotation period may use any part of such allotment at the next rotation period on giving five days' notice in advance.

W. HECTOR,
District Engineer.

Tatura,

By Authority: Albert J. Mullett, Government Printer, Melbourne

Fig. 4. Rotation Notice.

the Goulburn scheme, where water is supplied by gravitation, an increase of 30 cents per acre-foot would make the scheme entirely self-supporting and begin the creation of a sinking fund. A similar increase in the price of water in the Murray River Districts of Cohuna, Koondrook and Swan Hill, where, except at flood stage, the water has to be pumped, would meet all revenue requirements. Notice has been given that this increase may be made next year.

Rotation Period No...

Name of Irrigator..

Channel..

Delivery Commenced............................ a.m. p.m. ..../......................./.................

" Ended.................................... a.m. p.m ..../......................./.................

No. of Meter..................Diam. of Orifice..................inches.

Reading at End.... ....acre feet.

" Commencement...................................acre feet.

Quantity Delivered..acre feet.

Area Irrigated............................ acres.

Crop..No. of Watering...............

Fig. 5. Bailiff's Record of One Water Delivery Through Meter.

Officers in Charge of Water Deliveries.

Each district is under the control of a district engineer, who has charge of the work of the water bailiffs who turn on and turn off the water to the different users. A single bailiff controls deliveries to from 1500 to 4000 acres, the smaller areas being in the closer settlement districts, where the individual holdings do not average more than 30 acres. The water bailiff keeps a field book in which he enters daily the water delivered to the different irrigators, and later issues notices of these deliveries in triplicate. One notice is delivered to the irrigator, one kept by the water bailiff and one forwarded to the head office. Copies of the bailiff's field book record and of the triplicate notices are given below. (Figs. 5, 6 and 7.)

WATER BAILIFF'S DAILY REPORT.

Began Work / / a.m. Stopped Work / / p.m.

Channel ____________________

Flow in Channel ____________________ cusecs.

Level on Gauge at Head of Section ____________________ feet.

Quantity of Water Received ____________________ cusecs.

Level on Gauge at End of Section ____________________ feet.

Quantity delivered to Lower Section ____________________ cusecs.

Applications for excess water ____________________

____

____

Requests for Changes in Deliveries ____________________

____

____

Losses of Water or Delays in Deliveries—Causes of ____________________

____

____

Remarks ____________________

____

____

Signed ____________________
Bailiff.

13605. / /

Fig. 6.

Book No.

To be retained by Water Bailiff.

.... *District.*

STATE RIVERS AND WATER SUPPLY COMMISSION.

STATEMENT OF WATER DELIVERED.

Name of Irrigator..

Channel..Delivery No. ....

Outlet No.................................. Allot. No. .... Parish...

Dimensions of Submerged Orifice.................................ins. X.................................ins.

—	Date.	H. M.	Head by Gauge.	Time. Hours.	Delivery, Acre Feet.
Delivery Commenced ...		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
Intermediate Readings		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
,, ,,		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
,, ,,		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
,, ,,		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
Delivery Ended ...		..........a.m.	....	....	....
	....	..........p.m.	....	....	....
		Quantity Delivered			

SAMPLE

Crop	No. of Watering.	Acres.
....	....	....
....	....	....

Total Water Right...ac. ft.

Total Quantity Delivered to date... ac. ft.

(*Signed*)..*Bailiff*

Dated / /

B. 203/8.13.—11232.

Fig. 7.

Seepage and Evaporation.

Water is delivered and measured inside the boundaries of the irrigator's land. All losses from seepage and evaporation in distribution fall on the State. This varies widely in different districts. In the Rodney District the allotment is only three acre-inches per year for each acre of land, or enough to properly irrigate one acre in four. This means that water must be carried through four miles of channel to irrigate the land along one mile. The percentage of loss in this distribution is much heavier than where all the land has an adequate water supply and is all irrigated. In the Rodney District it requires about one thousand acre-feet of water a week to meet the seepage losses of water in channels. This does not vary much whether one thousand or five thousand acre-feet is delivered to users. The percentage of loss, therefore, depends quite largely upon the amount used.

In two districts, Merbein and Nyah, the seepage losses have made it necessary to cement many of the distributary channels. At present about half the water turned out of rivers is delivered to irrigators. The following is a copy of the water deliveries for the week ending October 24, 1914.

DISTRIBUTION OF WATER TO IRRIGATORS IN NEW SOUTH WALES.

In New South Wales, as in Victoria, the only important irrigation development is on the Murray River and its tributaries. The principal irrigation district is at Yanco, in the valley of the Murrumbidgee River, the largest New South Wales tributary of the Murray. In this district about 40,000 acres are now being irrigated, but canals to irrigate about 275,000 acres are building. The water will be taken, in part, from the natural flow of the Murrumbidgee and, in part, from a reservoir, which is now nearing completion which has a capacity of 766,000 acre-feet. The reservoir is located in the channel of the stream near its head, about 220 miles above the land to be irrigated, and water is turned down the river, as required, to supplement the natural flow. All the land to be irrigated was originally in private ownership, but has been purchased by the Government and is being opened up to settlement under perpetual leases, the State retaining the title and re-valuing the land for rental purposes

STATE RIVERS AND WATER SUPPLY COMMISSION.

RETURN OF DISTRIBUTION OF WATER for the Week ended Saturday, 24th. October, 1914.

District.	Total supply to district.	Delivered to users.	Discharged through waste ways or breaks.	Percentage delivered.	Percentage accounted for by delivery and waste.	Remarks.
Shepparton, No. 1 Estate	1102	734	10	66	67	
" No. 2 Estate						
Rodney	5747	3506	8	61	61	
Deakin	1237	732	-	59	59	
Tongala	1423	788	-	55	55	
Koyuga						
Rochester		1227				
Tragowel	2596	1057	(toKerang) 466	(Tragowel) 407	58	
West of Loddon (Boort)						
Coliban	370	124	133	34	70	
Cohuna	1690	758	150	45	49	
Gannawarra	1405	575	75	41	44	
Gannawarra West ...						
Koondrook	1484	708	-	48	-	
Kow Swamp ...	-	77	-	-	-	
Kerang	-	-	-	-	-	
Kerang Lakes ..	-	321	-	-	-	
Private Diversions ...	-	70	-	-	-	
Swan Hill	1099	772	-	70	70	
Nyah ...	238	211	-	88	88	
Merbein	580	390		67	67	
Dingee ...	162	129		80	80	
Bacchus Marsh ...	237	178	3	75	76	

Fig. 8. Record of Water Deliveries for One Week.

every twenty years. The holdings are small, averaging about 50 acres. Water is sold to the irrigators by volume and is measured by the Dethridge meter, which has been adopted in that State. The conditions under which water is delivered to this area and the price charged are set forth in the following regulation, adopted on August 11, 1914:

"Department of Lands,
Sydney, 11th August, 1914.

"His Excellency the Governor, with the advice of the Executive Council, has been pleased to approve of the subjoined amended Regulations, made by the Commissioner for Water Conservation and Irrigation, in pursuance of the powers conferred by the provisions of the 'Irrigation Act, 1912'.

J. L. TREFLÉ.

"REGULATIONS Nos. 22, 23, and 24, published in the Government Gazette of 16th July, 1913, No. 112, are hereby repealed, and the following substituted therefor.

L. A. B. WADE,
Commissioner.

"*Water Rights* (*Subsection e.*)

"22. Water, in pursuance of water rights, which are a fixed charge, will, during the season commencing on the first day of September, in one year, and terminating on the thirtieth day of April in the following year, be delivered to each farm in accordance with the Schedule of deliveries of water in the form of Schedule 'A', which shall be supplied to each lessee, but the quantity so delivered shall not exceed one-tenth of the total water rights granted for the season. Each occupier entitled to water shall, on or before each of the dates specified in the Schedule of deliveries (Schedule 'A'), fill in and forward to the office of the Commissioner on the Irrigation Areas a white printed card specifying in acre feet the volume of water required. Should the *white* card be delivered on a date subsequent to that set out in the Schedule of deliveries, then water will not be obtainable unless the occupier signs and gives an undertaking to pay the excess fee specified in Regulation No. 24. Any occupier requiring more water during a current delivery than has been ordered on the aforesaid *white* cards shall make application on a blue printed card. The additional water will then be supplied if deemed expedient by the Commissioner. Each occupier requiring special supplies of water between the regular deliveries (set out in the said Schedule of deliveries) shall make application by filling in a red card. The water will then be supplied if considered by the Commissioner expedient, but in every case a fee of five shillings (5s.) shall be payable by the occupier, in addition to the

charge for the water, to cover the expense incurred by the Commissioner. The prescribed cards coloured and printed as required by these Regulations shall be obtainable on application at the offices of the Commissioner in the Irrigation Areas, and when completed by the occupier shall be delivered at the said offices. No responsibility in connection with such cards shall be incurred by the Commissioner until the cards have been so delivered complete. Water, if required during the period subsequent to the thirtieth day of April, and prior to the first day of September, shall be supplied only by special agreement with the Commissioner.

"*Additional Water Rights* (*Subsection f*)

"23. Each occupier requiring additional water rights during the ensuing irrigation season shall make application for same in the form of Schedule 'B', and such application shall be delivered at the office of the Commissioner not later than the first day of July prior to the season in which such additional water rights are required. Additional water rights may then be granted and accepted in the form of Schedules 'C' and 'D', and if granted shall be delivered under the same conditions and during the same periods as provided under Regulation No. 22 for water rights which are a fixed charge. The Commissioner reserves the right to refuse any application, or grant such number of water rights only as he may consider fit.

"*Charges for Water Supplied* (*Subsection g*)

"24. The annual charges for water rights, which are a fixed charge, and for water rights, which have been granted and accepted as additional water rights, shall be payable at the end of each half calendar year in equal installments. Should the white card referred to in Regulation No. 22 be forwarded to the Commissioner later than on the dates specified in the Schedule of deliveries, the occupier shall be charged an excess fee at the rate of 1s. for each day after such dates up to and including the date of the receipt of the card by the Commissioner, but such excess charge shall not exceed 5s. Deliveries of water for which notice has been given in accordance with Regulation No. 22, if refused when duly offered, shall be deemed to have been supplied, and shall be charged for as such."

INTERSTATE AGREEMENT FOR DIVISION OF THE WATER OF THE MURRAY RIVER.

From Echuca to the mouth of the Murray, a distance of about 1000 miles, the river is navigable during certain months of the year, and claims for the perpetuation of navigation are continually maintained by the interests affected. The river is, however, diverted for irrigation and domestic purposes by all three States, and the time is approaching when these diversions will seriously reduce the period in which navigation is possible.

In order to prevent Interstate controversy and litigation, the authorities of the three States and of the Commonwealth, which has the right to protect navigation interests, met in conference in 1914, and prepared an Agreement, looking to the control of diversions from the Murray by an Interstate Commission composed of one representative from each State and one from the Commonwealth, the member for the Commonwealth to be the Chairman. This Agreement was signed by the representatives of the different States, but before going into effect has to be ratified by the Parliaments of the States and the Commonwealth. One State has already ratified it. The important features of the Agreement are:

1. Provision for navigation.
2. Division of the available water supply between the three States.
3. Apportioning the cost.
4. Providing for carrying the Agreement into effect.

1. **Navigation**: In order to perpetuate navigation, without sacrificing irrigation, the river had to be canalized, and in order to make this possible, the Agreement provides that 35 locks, in all, shall be constructed, which will be so located and have such height as to give a minimum depth of water in the river of five feet. The estimated cost of these locks is £3,105,000. When these locks are built, the water required to irrigate the lower districts will more than suffice to pass boats through the locks, and the only loss which navigation will cause will be the possible increased evaporation in the pools, and this will be so small as to have no material effect on the expansion of irrigation.

2. **Division of the Available Supply Between the Three States**: The Agreement provides that the three States shall construct two reservoirs to regulate the river's flow. One is to be constructed at the head-waters of the river; this is to have a capacity of 1,000,000 acre-feet, and the stored water is to be divided equally between Victoria and New South Wales. The lower reservoir, to have a capacity of 500,000 acre-feet, is to be built near the South Australian border. The approximate location of these two storages is shown in Plate I. These stor-

ages will be filled during the high-water flow and turned into the stream again at the time of greatest need.

With these two reservoirs in operation, it is believed that the Murray will furnish enough water to irrigate 1,400,000 acres of land. Of this supply, the allotment to South Australia is intended to enable that State to irrigate 200,000 acres, the remainder to go to the other States. To do this and to meet the channel and other losses, the Agreement provides that South Australia is to have each year a regulated allotment of 1,254,000 acre-feet of water, to be supplied to the State as follows:

134,000 acre-feet per month, during the months of January, February, November and December;
114,000 acre-feet per month, during the months of March, September and October;
94,000 acre-feet per month, during the months of April, May and August; and
47,000 acre-feet per month, during the months of June and July.

The two upper States will have whatever is left, and, approximately, it means that South Australia will receive a guaranteed supply of a little over one fifth of the available discharge, and New South Wales and Victoria each a little less than two fifths. The total cost of the storages and the navigation locks is estimated to be £4,663,000, and is to be borne in the following proportions:

Commonwealth	£1,000,000
New South Wales	1,221,000
Victoria	1,221,000
South Australia	1,221,000
	£4,663,000

The estimated cost of the several works involved in this Agreement is as follows:

Upper Murray Storage	£1,353,000
Lower Murray Storage	205,000
Locks	3,105,000
	£4,663,000

If this Agreement is carried into effect it will put an end to much uncertainty now existing and relieve irrigation interests of the menace of costly, uncertain litigation. It has been ratified by two States, New South Wales and South Australia and the Commonwealth Government has stated that it will approve, as soon as it has been ratified by all of the States. The matter was still pending in the Victorian Parliament when this report was written.

DISCUSSION

Mr. Duryea.

Mr. Edwin Duryea, Jr.,* M. Am. Soc. C. E. (by letter), stated that he had not attempted to write a discussion of Mr. Mead's paper but did wish to point out the three important points brought out in the paper, to-wit:

(a) The absolute necessity of irrigation in Australia, in order to furnish fodder to stock during dry seasons;

(b) The scarcity of water in comparison with land in Australia, and the consequent careful use of the water-supply which is being developed by the aid of several kinds of irrigation water-meters;

(c) The fact that in Australia, as in Italy, Spain and the United States, it is apparent that the furnishing of irrigation is hardly a commercial problem, and that to be a success it must be aided in some way by the State, especially during its early years.

* Cons. Engr., San Francisco, Calif.

Paper No. 44

IRRIGATION IN SPAIN.

Distribution Systems, Methods and Appliances.

By

J. C. STEVENS, M. Am. Soc. C. E.
Portland, Ore., U. S. A.

An irrigation system consists essentially of three parts: (1), a source of supply and methods of diverting water; (2), the main canal, which may be divided into several principal branches; and (3), the distribution system.

The "distribution system" is a general term and does not always convey the same significance on all projects, although the primary function of a distribution system is always the same, viz., that of distributing the water from the main canal system to the individual tracts to be irrigated. The plan is exactly analogous to that of the corresponding system in city water supply, where a system of smaller pipes delivers the water from the main pipe lines to the several houses and buildings. On the irrigated lands, however, the distribution is effected by open ditches, wherever possible, instead of in closed pipes, on account of the lesser cost.

In Spain, the distribution system of an irrigation project has the same functions to perform as in all irrigated countries, the only difference being, that, compared with the United States, the system is generally more complicated, especially on the older projects, owing to the smaller sub-division of the lands and the fact that all land for cultivation is leveled. By this, it is not intended to convey the impression that Spain is a level country. The facts are quite the contrary.

Perhaps nothing attests more strongly to the indefatigable energy and industry of the agricultural population of Spain as the statement that all lands are leveled before any attempts at cultivation are made. A traveler in Spain is struck at once with

the immense amount of work that has been expended in terracing the steep slopes of hills and mountains. On hillsides, stone walls are first built contouring the slopes, and between them the soil is deposited until the entire area to be cultivated is perfectly level. Some of these walls are nearly three meters in height and spaced as close as twelve or fourteen meters apart, so that a terraced hillside has the appearance of a mighty stairway.

On the more rolling lands, broader terraces are possible with much lower walls, but the same general scheme of terracing is adhered to. Even the slight grades that prevail downstream in the flood plains of small creeks or "barrancos" are frequently brought to a dead level by terracing. In such cases, the walls are built and the soil is frequently allowed to assume its own level between them from the wash of rain and overflow. The essential feature to keep in mind, however, is that all cultivated lands are level, no matter whether the land is irrigated, or farmed by the dry farming processes.

The problems that arise in the designing of a distribution system to water lands thus terraced are somewhat different from those encountered in the United States, where such practices are unknown. The main laterals of the system are, of course, constructed on the same plan as those of all systems; that is, the water must be brought to the commanding heights in sufficient quantities to water all the lands that slope from those heights. From these main laterals, the sub-laterals carry the water to the secondary prominences, from which the smaller ditches deliver the water to the several farms and terraces. In reality, therefore, the differences in the distribution system between deliveries to natural lands and to terraced lands do not come prominently into play until the finger-tips of the system are reached.

The organizations under which irrigation projects are constructed and administered play no small part in determining the form and efficacy of the distribution system. In general, the main canals and the principal laterals are built and operated by one organization, and the secondary laterals and the remainder of the system are built and administered by another. The first organization may be the government or a company

having concessions from the government. The second organization generally consists of a syndicate or association of the farmers themselves. The construction they perform is partly, or wholly, done under the direction of the first organization, and usually according to general plans evolved by it. On many of the older projects, however, general plans were never evolved, and little attention was paid to the work performed by the Association, the Company feeling that its duty had been fulfilled with the completion of the main canal and principal laterals. The result can well be imagined to lead to endless difficulties, strife and jealousies between the two organizations.

The writer cannot better illustrate the points that have been touched upon in the foregoing description than by describing two large irrigation systems that exist side by side in the eastern portion of Spain. One, the Urgel canal, is representative of the older type of irrigation projects, built by a company under concessions from the Spanish Government; the other, the Aragon canal, built in recent years by the Government itself, is illustrative of the more modern achievements in irrigation practices.

THE URGEL CANAL.

The Urgel canal waters the plains of Urgel, lying in the eastern part of the province of Lerida, the heart of the district being about 100 kilometers due west from Barcelona.

Many and varied were the vicissitudes attending the promotion and construction of this project, that covered a period of over 350 years. The project was first conceived during the reign of Carlos I, about 1540. Between 1554 and 1577, Filipe II caused surveys to be made by his treasurer, Matin J. Franqueza, who was also instructed to collect taxes from the residents of the district, to be used in construction work. But Franqueza lost interest in the project and his work remained unfinished. Under Filipe III a tax, consisting of a certain portion of the crops, was imposed for constructing the canal, but an unprecedented drought caused the loss of the crops and the tax was never collected. In 1739, an association was formed, new plans were begun and a loan negotiated for, but was never paid.

In 1749, under Ferdinando VI, a new plan was evolved, but there arose such vigorous objections to the project, based upon a belief that the work would be inimical to the public health, that it was abandoned.

Carlos III, following a joint demand from the commercial organizations of Barcelona and the Sociedad Economica of Tarrega, completed a survey, and made an estimate of the cost amounting to 4,000,000 pesos, under a belief that the canal was for navigation. Some of the maps of the country still show this projected "navigation canal".

Some actual work was begun in 1814 by Tomas Soler, who obtained a concession to collect from the farmers of the district a thirtieth of their fruit crops and a special tax on imports into Barcelona. The plan failed for lack of funds.

New plans were made in 1825 and abandoned in 1833. A sickening succession of failures occurred during the next 20 years, in which no less than five plans to finance, were tried without success.

Finally, in 1853, the Sociedad Canal de Urgel obtained a concession for the construction of the canal, excepting the difficult tunnels, and began construction in 1853, in order not to forfeit the concession, with an estimated cost of 1,600,000 pesos. In 1859, the studies of location had not yet been completed, but the estimate of cost had been raised to 2,900,000 pesos.

The *pièce de résistance* of the entire project was the tunnel of Monclar, 4897 meters in length, that required 8 years for its completion, and cost 1,325,000 pesos, or nearly as much as the original estimate for the entire project. To excavate the tunnel, there were begun 30 shafts, but the tunnel was completed before some of the shafts had been finished!

The canal was practically completed in 1865, and water was made available for the lands. The system today comprises a main canal 150 kilometers in length, and four principal laterals, built and operated in connection with the main canal by the Sociedad Canal de Urgel, having an additional length of 100 kilometers. The distribution system begins with the four principal laterals and is operated by another organization. It comprises a total length of 2800 kilometers, so there is in use on this project over 3000 kilometers of canals and laterals, covering a total of 70,000 hectares of land.

The distribution system was built and is operated by an association of the irrigators, under the project called the Sindicato de Regantes, equivalent in all respect to the Water Users' Association of the Reclamation Service projects in the United States.

The two organizations perform their several functions according to the terms of an agreement made Feb. 17, 1862, called the Convenio de Madrid. The essential provisions of this agreement are:

The water users are obliged to pay to the Sociedad each year one ninth of all fruit crops and certain other cash payments for forage crops during the first 60 years of the Royal Concession—which is for 99 years, beginning in 1852—and four per cent during the remaining thirty-nine years.

The Company (Sociedad Canal de Urgel) is obliged to supply to each hectare under the system 3100 cubic meters of water in the nine months from September to May, inclusive, each year. This is equivalent to a depth of 31 centimeters (one foot).

During the remaining three months (June, July and August), the Company is obliged to carry in the canal, and to distribute proportionally among ten well-selected points throughout the system, as much water as possible without danger to the canal and without danger of violating the provisions of the previous clause. In this period, preference must be given to irrigation over service for industries.

In case the Company is unable to deliver the required amount of 3100 cubic meters of water per hectare, the fault lying with the project, the amount which the irrigators shall pay to the Company shall be reduced to an amount proportional to that actually delivered.

The next question that naturally arises is, how have the people prospered under this system during the 52 years this contract has been in existence? The general appearance of the farms under the system is one of moderate prosperity. The farmers under the system are moderately well to do. Their lands are intensively cultivated, representing an enormous expenditure of time and labor; labor, in fact, for which there has been but slight compensation; a bare moderate living, if you please, and nothing more.

The Company is in a condition bordering on bankruptcy, and is attempting to have the contract rescinded and payments made in cash instead of in produce.

The quantity of water delivered is altogether insufficient for the crops to be raised. The following table shows the quantity actually carried in the canal, in terms of the depth over 62,000 hectares:

Depth in Meters of Water Applied to Lands of Urgel Canal.

	1906-7	1907-8	1908-9	1909-10	1910-11	1911-12
Nine months, Sept. to May	0.31	0.20	0.35	0.39	0.46	0.41
June, July and August	0.14	0.19	0.15	0.15	0.18	......
The year	0.46	0.39	0.50	0.54	0.64	......

Not all the water above noted was actually applied to the lands, as the figures include seepage and waste from the operation of the system. There are, in addition, a number of small water power plants on the four principal laterals to which water is furnished. These plants utilize the irrigation water, but at times, during the winter months, water is run through the canal expressly for these plants and wasted back into the river, not being used for irrigation. Such water, although relatively small in amount, is included in the above figures.

It is doubtful if the land receives, on the average, over 40 centimeters (16 inches) of water, in depth, per year. This quantity is entirely inadequate to grow crops successfully in this climate and soil.

The fact is that the amount of water above cited is not equitably distributed among the 62,000 hectares. The lands lying in the upper part of the system, that is, nearest the head, receive an undue proportion of the water, and those at the lower end suffer. The result is that in the upper portion of the system the farms are thrifty and comparatively well-to-do, while in the lower portions the country is but one degree better than a dry farming district.

As has been stated before, the distribution system begins with the work under the direction of the Sindicato de Regantes, or Water Users' Association, and it is the business of this Asso-

ciation to keep the entire distribution system in repair, and to construct extensions thereto when required.

During a period of 30 days or six weeks, usually in January and February, water is turned out of the canal at the headworks and the entire system drained, to permit cleaning the main canal and the laterals. This work is divided into divisions and supervised by the Company, which pays for that done on the main canal and four principal laterals. The larger laterals of the distribution system are cleaned at the same time, at the expense of the Association.

During this cleaning period, every meter of the canal is gone over carefully, all silt, debris and plant growth are removed, and any needed repairs to banks, culverts, bridges, flumes or aqueducts are attended to.

The actual methods of applying water to the lands are those usually followed in all irrigated countries. Wherever the land is naturally sloping, that is, where terracing is pronounced, flooding is generally resorted to for grains and forage crops. In orchards, water is conducted to each tree in small ditches. In truck gardening, the water is run in the furrows.

On account of the terraces, no lateral can pass boldly across the country, as is frequently possible where terraces do not exist. Instead, the main laterals are located on the ridges, or along the sides of the valleys, just above the terrace walls. Branch laterals lead off at the upper edge of each terrace, or if laterals are located across a series of terraces, drops are provided at each point where a wall is crossed.

CANAL DE ARAGON Y CATALUNA.

The Aragon canal is typical of the more modern irrigation projects in Spain. The system was built by the Government, after a private company had attempted the construction and failed, for lack of funds, to complete the works begun.

The canal was nominally completed in 1909, following a construction period of about 13 years. Money for the construction was made available by direct appropriation of the Spanish Government.

The canal covers a total of 105,000 hectares of land, lying both in the province of Lerida, and the province of Huesca.

Lerida is a part of what was anciently known as ''Cataluna'', and, similarly, Huesca is a part of ''Aragon''. Neither of these principalities now exists as a political entity, but the names are preserved, and the boundaries exist as a matter of history only.

The Aragon canal diverts water from Rio Esera, a tributary of the Cinca, which is, in turn, a tributary of the Segre, from which the Urgel takes its supply. The two canals are thus seen to exist under the same climatic conditions; in fact, they water lands lying on opposite sides of River Segre.

The main canal is 120 kilometers in length, with an initial capacity of 35 cubic meters per second. At kilometer 34, heads its principal branch, called Canal de Zaidin, which is 60 kilometers in length, and has an initial capacity of 15 cubic meters per second. From this main system, head several principal laterals, that have a combined length of 180 kilometers. Thus the main arteries are seen to have a combined length of 360 kilometers, before the distribution system proper begins.

The distribution system begins with the portion under the direction of the Sindicatos, or Associations, as is the case with the Urgel canal. The main canal and the principal laterals that conduct the water to the principal points of use have been built by the Government, leaving the individual or community ditches to be built under concessions granted by the Government.

A large part of the land under this system is new, and the extensive terracing that is seen in all agricultural sections is not yet an accomplished fact. Terracing, however, is progressing at a rapid rate, and it will not be many years before all cultivated land under this project is level.

The duty of water under this project is fixed by law at 0.33 liters per second, for each hectare. This quantity, however, is not the amount delivered to each hectare, but is the amount of water granted the canal system by the Government; that is, the canal has a water right to 0.33 liters of water per second for every hectare of land that can be brought under the system.

The duty of water on the land is not fixed. The system of ''pay-for-what-you-consume'' is practiced on this project, and the amount of water that anyone can have is limited only by the amount he can safely carry in the laterals, and the amount

he is willing to pay for. The methods of accomplishing this are set forth in another article.

The same method of cleaning the canals and laterals prevails on this system as has been previously described for the Urgel canal. The water is turned out of the canal for a period during the winter months, usually during January and February. The individual and community ditches are cleaned by the farmers themselves, while the rest of the system is cleaned by the Government, employing the local farmers as laborers.

PERMANENCY OF CONSTRUCTION.

There is one point that should be emphasized as being quite at variance with the practice in the United States. That is the permanent character of the structures. Practically no wood is used in the structures of irrigation works in Spain. All bridges are masonry arches or of reinforced concrete, with occasionally a steel bridge where the span is long. All flumes are of masonry or concrete. Even the small flumes on individual farmer's ditches are frequently made of a succession of cut stone, hollowed to the form of a trough. These may be two meters in length and supported on stone posts set under each joint.

Masonry flumes or aqueducts are quite common throughout Spain; some of them built in the times of the Roman conquerors, are still doing service today. All such structures, whether ancient or modern, are built with the idea of being ornamental as well as useful. In some of them, it would almost seem as if the ornamental side has been given too much weight. Simpler and plainer structures would in many cases have served the required purpose fully as well, presented an appearance of simple dignity and have cost far less.

The four cuts will give an idea of the character of works representative of the latest type of construction in Spain. Fig. 1 is typical of the masonry arch, highway bridge. This is one of the highway crossings of the main Aragon canal. Fig. 2 shows a simple reinforced-concrete bridge over the Canal de Zaidin, the principal branch of the Aragon canal. This structure is commendable in its simplicity, and is in no respect subject to the charge of excessive ornamentation.

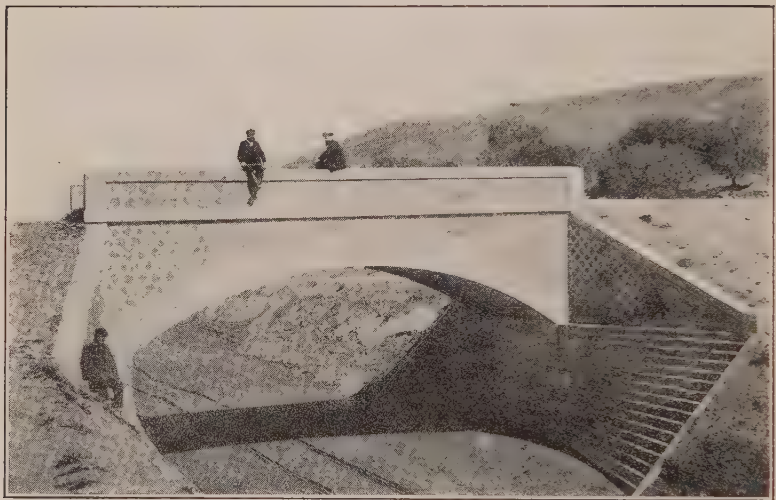


Fig. 1. Highway Bridge across the Main Aragon Canal.

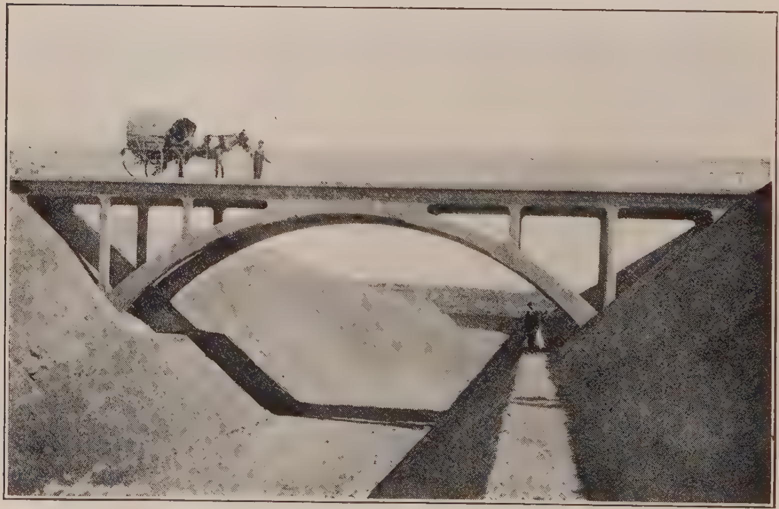


Fig. 2. Reinforced-Concrete Bridge across the Canal de Zaidin.

Fig. 3. Sosa Siphon, Aragon Canal.

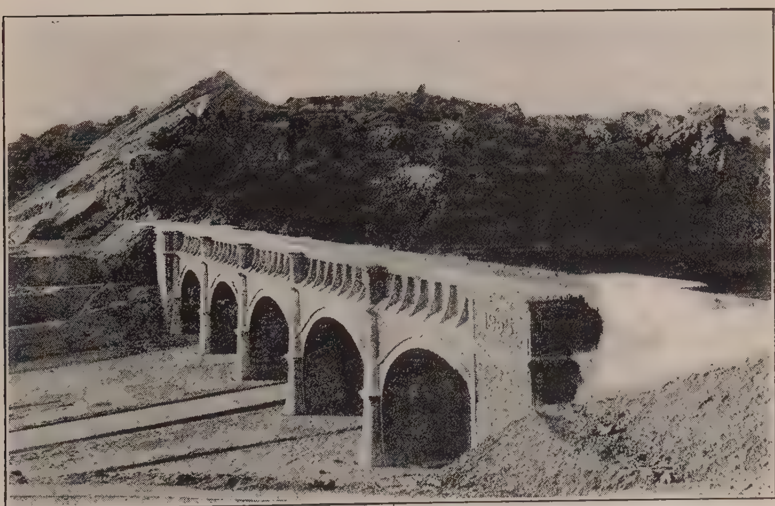


Fig. 4. Reinforced-Concrete Aqueduct on the Main Aragon Canal.

Fig. 3 shows a downstream view of the famous Sosa Siphon, of the Aragon canal, one of the notable engineering structures in Spain. This inverted siphon has a capacity of 35 cubic meters per second, which it carries in parallel reinforced-concrete pipes, each 3.80 meters inside diameter. The pipes are 1018 meters in length, with a maximum depression below the water surface in the canal at the inlet of 28 meters. At the point of crossing the bed of the river the pipes are carried on the ornamental masonry arch bridge shown in the figure. It is safe to say that a large percentage of the cost of this structure is for ornamentation that could have been saved without loss of dignity or usefulness.

Fig. 4 shows an ornamental aqueduct of reinforced concrete, supported by massive concrete arches. This structure also occurs on the main Aragon canal and has a capacity of 35 cubic meters per second.

These structures are typical of public works in Spain. They are not confined to irrigation works, but are found in connection with Government-built highways; with railroad structures built by private capital; in fact, in all structures for public service.

On irrigation works, excessively ornamental structures can not be defended. The land is brought under subjection at the cost of a large amount of money. A successful project almost invariably has achieved success at the cost of one or more previous failures. The first years represent a struggle for a bare existence, until the lands can be subdued and made to respond to water and cultivation. It would seem, therefore, that the struggling farmer might be spared the additional burden of paying for monuments to somebody's vanity.

DISCUSSION

Mr. Duryea. **Mr. Edwin Duryea, Jr.,*** M. Am. Soc. C. E. (by letter), stated that Mr. Stevens' description of irrigation in Spain is of great interest to irrigation engineers in other countries.

The careful terracing and levelling of the irrigated land so common in Spain is practically unknown in America, though said to be the common practice in China. In California the latest and best method of preparing the land is by "border checking", or by dividing the land into narrow

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strips running up and down the slope and levelling each strip only transversely or parallel to the contours. Mr. Duryea.

The method used on the Aragon Canal of paying for the irrigation, that of paying in proportion to the amount of water used, is to be highly commended. It is believed that a similar practice in the irrigation districts of California (where as yet the water is paid for at a uniform rate per acre, irrespective of the amount actually used) would check effectively the waste and excessive use of water and thus prevent most of the resulting injury to the land from swamping and rise of alkali. Payment for irrigation in proportion to the amount of water used is not practicable under the present irrigation law of California; but it would not be difficult so to modify the law as to permit a base charge for irrigation at a uniform rate per acre for a stated reasonable maximum depth of water, plus an additional charge per acre-foot for all excess water used.

The masonry irrigation structures so usual in Spain are usual also in Spanish-American countries, as in Mexico. It is doubtful, however, if this practice is primarily due to the desire for permanency. In Mexico, at least, labor and materials are in general more plentiful and less costly for masonry than for wooden structures. Recent comparative estimates by Mr. Duryea show that in the state of Chihuahua, Mexico, small irrigation-structures can be built of lime-masonry at a cost as low or even lower than of wood.

While permanent irrigation structures are less common in America than in Spain, it is increasingly becoming the practice in California to replace the wooden structures by permanent ones when rebuilding becomes necessary—as is the practice in structures now of many American railroads. As examples, the Turlock and Modesto Irrigation Districts for several years past have been replacing wooden flumes on high wooden trestles by concrete-lined canals on settled earth embankments or by reinforced-concrete flumes and trestles; and the South San Joaquin Irrigation District (system built in 1911-14) built all the irrigation-structures on the main distributary canal of its distribution system (about 30 structures on 12 miles of canal) of reinforced concrete—but built practically all the structures on the remaining 350 miles of its distribution system (more than 3000 structures) of wood, with the expectation of rebuilding them gradually in concrete as they require replacement.

It is of great interest to learn from Mr. Stevens' paper that in Spain commercial irrigation companies are not as a rule financially successful, and that in most instances State aid in some form is a necessity to the success of large irrigation developments. This general lack of success of commercial irrigation companies has been the experience also in Italy and in the United States of America.

Mr. J. C. Stevens, in closing, said that the question of permanent construction raised by Mr. Edwin Duryea, Jr., is one that might attract the attention of the traveler in nearly all European countries. He is of the opinion that in Spain this is partly done from a desire to secure permanency of construction and partly because masonry work is secured Mr. Stevens.

Mr. Stevens. there at somewhat lower cost than it can be secured in this country. Building stone of various kinds is plentiful; lumber is expensive and cannot be secured in proper dimensions for heavy construction work. The use of lime mortar in Mexico, as mentioned by Mr. Duryea, has been noted by the author in Spain on a great many structures; some of the old ones built by the early Romans, wherein lime mortar was used, are still intact.

The author was engaged for two and a half years on the construction of large hydro-electric developments along the Ebro River and tributaries, to serve the city of Barcelona and outlying districts. In this work they were obliged by the Department of Public Works to make all structures of a permanent character. All bridges were of concrete or of steel; canals were all concrete lined; power houses were all of reinforced concrete with concrete floors and roof. No wood was used in any portion of the work. This added greatly to the cost over what would have been possible in this country. There is a question whether it is not cheaper in many instances to build some structures of timber and replace them, rather than pay the heavy interest charges on first cost of permanent construction. However, the use of masonry in the Spanish countries dates from the earliest records of construction and the State officials, contractors, railroad companies, and in fact all parties engaged in or having to do with construction are so thoroughly accustomed to designing everything of permanent material that it is useless to talk temporary structures in face of such well-established habits. To illustrate, on the hydro-electric work previously mentioned, steel flumes with steel substructures were not allowed to be used for certain portions of the power canal on account of the possibility of the thin metal wearing through by the sand and silt carried in the water. In other words, steel flumes that in this country are considered more or less of a permanent nature, in that country were considered too temporary.

Paper No. 45

IRRIGATION IN SPAIN.

Regulations Controlling the Use of Water, Metering Water for Irrigation and Methods of Charging.

By

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Mention has already been made in another article, "Distribution Systems, Methods and Appliances", of the two largest canal systems in Spain, the Urgel Canal and the Aragon Canal, the former representative of the older type and the latter typical of more modern practice. The regulations in force and the methods of measuring and charging for the water consumed on these two projects so aptly illustrate the Spanish practice, that a description of these two systems will fulfill completely the object of this paper.

THE URGEL CANAL.

As stated in the article above mentioned, this canal was completed in 1865, by a private company operating under a concession from the Spanish Government. The canal, today, but imperfectly waters a total of 62,000 hectares of land. The main canal and the four principal laterals have a combined length of 250 kilometers. The distribution system comprises all the remainder of the system, and represents a total length of nearly 2800 kilometers of ditches.

The main canal and the four principal laterals are owned and operated by the company called Sociedad Canal de Urgel. The distribution system is owned and operated by an association of irrigators under the system, called the Sindicato de Regantes.

Operation is conducted under the terms of a three-cornered contract between the Company, the Association and the Govern-

ment. This agreement is known as the Convenio de Madrid, and dates from 1852, with a life of 99 years.

The method of making payment for the water furnished by the Company is nominally simple, and something of an innovation. In practice, it has not worked satisfactorily, as attested by the fact that the Company is in a state bordering on bankruptcy. The Convenio de Madrid obligates each farmer who takes water from the Company's canal to subscribe to the terms of the Convenio and to pay to the Company one ninth of all fruit crops, and certain cash payments for truck gardens and alfalfa. Wheat and other grains are included as "fruits". In addition, the Company has all the income from the sale of water for water power plants, of which there are several small ones along the principal laterals.

The net income from this contract is usually less than 2% on the total cost of the project to date. The average of seven years, 1905 to 1911 inclusive, shows the following financial statement:

Average gross income	$210,300.00
Administration expenses (includes operating expenses, repairs and betterments, but no payments on outstanding indebtedness)	110,300.00
Net income	$100,000.00
Per cent of capital invested ($6,000,000)	1⅔

The advisability of modifying the Convenio de Madrid has been discussed many times, the right to do which is reserved to the Government, but there seems to be no possibility of reaching an agreement between the Company and the Association. Conditions under the system are admittedly bad, but there seems to be no immediate remedy in sight.

There are absolutely no means of metering the water under this system. In a careful examination, made on foot, of the first 75 kilometers of the main canal, and wide detours through the irrigated sections, the writer did not see one device especially constructed for measurement of water. At the heads of the principal laterals there are substantial headgates, from the openings of which, and the depth of water in the canal, the flow into them can be approximated. At several points along the main canal, gauges were installed. Readings of these are recorded

every day by the patrolman. From some of these, particularly at the Cenil aqueduct, the flow can be calculated from the hydraulic elements of the canal section. Aside from these, there are no methods of measuring the flow. These portions belonged to the Company. The distribution system is absolutely without means of metering its water.

Only the crudest sort of headgates exist at the farmers' laterals, and these are entirely inadequate for measuring the amount of water diverted to his individual use. Yet in their rude, "rule-of-thumb" way some sort of division of the water is arrived at that seems to be satisfactory to the farmers themselves.

The Company is obliged to supply to the lands under the system sufficient water to cover the land to a depth of 31 centimeters, during the nine months from September to May, inclusive. This is required by the terms of the Convenio. During the months of June, July and August, the Company, by the same contract, is obliged to carry all the water it can to the lands, giving preference to irrigation over use for power. In the article mentioned at the beginning of this paper are given the quantities actually applied to the lands in recent years, showing that an average quantity equivalent to a depth of 40 centimeters over the total irrigable area under the canal (62,000 hect.) has passed the intake of the canal. This quantity is insufficient for the production of crops, with the result that a portion of the lands receives an undue proportion of the water, and others suffer from lack of water. This natural tendency of human beings to "hog" the water, where water is scarce, is aided and abetted by the fact that there are no provisions for equitable measurement of the water among the several users.

The distribution of crops under the system, in 1898, was as follows:

Grains	17,182 hectares	
Alfalfa and other forage	2,190 "	
Truck gardening	187 "	
		19,559 hectares
Grapes	6,979 hectares	
Olives	14,432 "	
		21,411 "
Grand total		40,960 hectares

The first sub-total, of 19,559 hectares, represents the crops that require copious irrigation, while the second figure, of 21,411 hectares, for grapes and olives, represents crops that thrive on a minimum of water, and frequently get only such moisture as they may from seepage water. Fairly creditable crops of olives and grapes are frequently raised in the district without irrigation. These figures are taken from the annual reports of the Company and show all the lands from which payment was obtained for water furnished. The conclusion is obvious; with 62,000 hectares "signed up" under the system, only 41,000 received water sufficient to make payments, and of this 41,000, only one half (19,559) was in crops that required any appreciable quantity of water. If we assume that the average quantity of water was supplied during the year in question, the distribution was probably such as to give a depth of 1.00 meter on the 19,559 hectares, and 0.25 meter on the 21,411 hectares of grapes and olives. The remaining 21,000 hectares of land under the project did not receive water at all, although these lands had "signed up" and were required to pay the one ninth of their crops in other years, when there was sufficient water to go around.

The Urgel situation is very tersely summed up by Manuales Soler, Ex-Director Canal de Urgel, in his work "Canales de Riego", from which the following translation is made:

"The Urgel Canal lacks, point by point, all those elements that go to make irrigation in Northern Italy so successful.

"The project was conceived and work begun before surveys and estimates had been completed; without having thought of the indispensable supplementary structures; without plans; without knowing the irrigable area or character of the land and the inherent difficulties that encompass a project of such magnitude.

"There is lacking storage of water for the summer months and regulation of the flow at all times; the people under the project lack the proper incentive to work, so necessary in an irrigated country; there are lacking highways of communication, well-to-do agriculturists, instruction in the technique of irrigated farming, institutions of rural credits, and a proper division of proprietorship. They have staked their all on the virtues of the water alone. Is it any wonder that failure should have followed such lack of foresight, such negligence?"

CANAL DE ARAGON Y CATALUNA.

We pass now from a system that lacks so many of the elements of success, a system practically without regulation, without measurement of water consumed, with a hopelessly impracticable system of charging for water delivered, to one in which regulation is well-nigh perfect, where water is measured to the last finger-tips of the system, and the only rational payment method, the "pay-for-what-you-consume system", is in force.

The Aragon canal was built by the Spanish Government, and is now being operated by the Department of Public Works. It was begun in about 1896 and completed in 1909. There are in all 149,000 hectares of land lying between the system and the rivers Cinca and Segre. About 23,000 hectares are watered from small ditches taking water directly from the rivers; 21,000 hectares lie above gravity flow, or, otherwise, are unfit for cultivation; leaving a net irrigable area of 105,000 hectares, all of which is covered by the main canals and principal laterals already constructed.

These lands when completely cultivated will be divided about as follows:

Grains (wheat, rye, oats, barley, peas, etc.)	75,000	hect.
Olives and vineyards	15,000	"
Truck gardening and intensive cultivation	15,000	"
	105,000	"

In 1906 the number of hectares actually watered was 5990 and in 1914, 55,380 hectares were irrigated under the system. Additional lands are being brought under cultivation every year.

Physical Features.

The Aragon canal takes its water from Rio Esera, a tributary of the Cinca. It carries its waters from the intake for a distance of 5 kilometers through a rugged mountainous country, necessitating many tunnels and aqueducts before it begins to deliver water for irrigation. In this stretch, it has a maximum capacity of 35 cubic meters per second. At Kilometer 6 it enters the valley of the Cinca, a heavily rolling country but quite generally cultivated. Gradually leaving this valley, the canal ex-

tends itself to the eastward along the foothills bordering the immense Plains of Aragon, and enclosed on three sides by the rivers Cinca, Segre and Noguera Ribogorzana.

At Kilometer 31, it crosses the valley of Rio Sosa in the famous "Sifon de Sosa", consisting of twin tubes of reinforced concrete, each 3.80 meters inside diameter and 1018 meters in length. At Kilometer 34, the first principal branch heads. This is called the Canal de Zaidin and carries 15 cubic meters of water. The remainder of the water continues to Kilometer 120, where the surplus is wasted into River Segre. At Kilometer 57, the flow is reduced to 18.50 cubic meters, and this quantity passes the Valley of Albelda in another famous structure, the "Sifon de Albelda", also of reinforced concrete. This is a single tube of 4 meters inside diameter and 725 meters in length, and has a maximum depression of 30 meters. Unlike the Sosa siphon, however, this tube is buried in the ground throughout its length, instead of being supported by a bridge at its lowest point, as is the case with the Sosa siphon. (See Fig. 3 of article referred to at beginning of this paper.)

Beyond Kilometer 82, the canal has the name Canal de Escarpe, although it is in reality a continuation of the main canal.

From the main canal, there are four principal laterals; from the Canal de Zaidin there are three; and from the Canal de Escarpe, there are five principal laterals, constituting a total canalization of 292 kilometers that have been built at the expense of the Government. This constitutes an entity, the exclusive property of the Spanish Government.

From previously determined points on the above system, concessions are granted to associations for the construction of laterals and the diversion of water therefrom. It is at these points that the distribution system properly begins, the construction of which is done at the expense of the grantees of these concessions.

Organization and Regulations.

The operation of the Canal and its administration are under the direction of a director, who reports to the Chief of Public Works in the Province of Lerida. (The present director is Sr. D. Alfonso Benavent, Lerida, Spain.) The administration office

is located at Monzon, near the upper central portion of the system.

The canal is divided into a number of divisions, called ''fielatos'', each being in charge of a superintendent, called ''Fiel de Agua''. Each superintendent has under him from four to six ditch walkers, and, in addition, a sufficient number of gate-tenders to operate the headgates in his division.

Each superintendent is furnished a house and a tract of land. The house contains space for his office. He is essentially an office man, being obliged to go personally over his division but once a week. The ditch walkers are continually on the canals and ditches under their direction, and report frequently to their superintendent with whom they are in frequent telephonic communication. The senior superintendents, of whom there are ten, receive about $0.85 per day, the remainder about $0.70. There are as many superintendents as there are divisions of the canal system, and as many more as are required for the central administrative office, and supernumeraries. At present there are 28.

The ditch walker, ''acequiero'', is a police officer and a laborer. He has all duties pertaining to the operation and regulation of his section of the system, under the orders of his superior.

The gate-tender, ''compuertero'', is also a police officer and laborer, and has charge of the gates at the intake of the main canal and at the important branches and regulating gates, spillways, etc., and opens or closes them at the direction of the superintendent.

All superintendents, ditch walkers and gate-tenders wear prescribed uniforms, which they are obliged to furnish at their own expense, except the buttons and insignia of rank.

The administration never deals directly with the farmers themselves. Instead, the farmers are organized into Associations, called ''Sindicatos'', each of which has its president, secretary, treasurer and police officers. All negotiations between the farmers and the administration of the canal are carried on through the officers of the Associations and the superintendents of the canal system.

The entire canal system has been definitely laid out and the possible extensions to the distribution system are definitely determined. Whenever a community wishes to make an extension

to the distribution system, it organizes itself into a "Sindicato", or Association, and petitions the director of the canal for a concession to construct lateral "so and so", designated on the approved plans of the project.

The headgate is constructed by the Government, after a deposit has been made by the concessionaire to cover the estimated cost of the work.

From these community laterals, individual farm laterals are constructed by the farmers themselves, but they must first make arrangements with the Association, which will grant them a right to construct under certain regulations. In this respect, the distribution system is the exclusive property of the several Associations. The laterals come to bear the same relation to the lands under them, and the regulation of water is accomplished in the same manner, as with the main system. Each farmer is thus responsible to the Association of which he is a member, and each Association is, in turn, responsible to the administration of the canal.

Metering of Water.

Water, under this system, is sold at so much per cubic meter, hence it is absolutely essential to measure it at all points of diversion and use.

Here, again, a suitable division of authority and responsibility makes this possible. The administration of the canal, dealing only with the several Associations, measures the water delivered to the head of each lateral built under a concession, and the Association measures the water delivered to the individual users forming the Association.

The main canal is measured at the point of diversion from Rio Esera. Measurement at this point is made by means of the headgates. The gates are assumed to form submerged orifices, the areas of which are known from the gate openings which are recorded. The heads on the orifices are determined from the reading of gauges set in the river just above the diversion dam, and in the gate house just below the gates.

At several other points along the canal, suitable sections have been chosen where the flow can be calculated by means of slope formulae, knowing the depth of flow, which is readily de-

termined from gauge readings. In this manner, the flow in the main canal is determined daily, or oftener, at all important points in the system. Suitable tables have been prepared, from which the flow can be determined directly from the gauge readings reported by the several superintendents by telephone.

At the points of diversions into laterals of all sizes, the flow is determined by calculations, assuming the open gate to form a free orifice. Near every delivery point is a gauge in the main channel that gives the depth over the sill of the gate. The gate opening is measured and the flow determined from prepared tables. In order to facilitate this method of metering, all the gates are of a standard size, the number only being varied with the amount to be delivered.

At the intake of the main canal, the head of the Zaidin canal, and other large deliveries and wasteways, the gates are all 1.00 meter in width. On the concession laterals, the gates are 0.30 meter in width for vertical gates and 0.50 meter for gates inclined at 45 degrees, the slope of the canal lining. Wherever the quantity of water calls for a large flow, the regulation gate of 1.00 meter is installed.

Printed tables have been prepared, giving the flow of water in liters per second through gates of 1.00 meter; gates of 0.30 meter, vertical; gates of 0.50, inclined; and double gates of 0.30, and 0.50 meter each; for gate openings varying by centimeters from 0.01 to 0.50 meter; and for depths in the canal, varying by 5 centimeters, from 0.20 meter to 3.00 meters.

Each superintendent, ditch walker, gate-tender, and the corresponding officers of the Associations, are supplied with these books. Each ditch walker and gate-tender reports daily, or oftener, to the superintendent the gate openings and gauge readings of all diversions under his direction. These data are telephoned to the main office at Monzon, where the flow is entered on suitable forms and credited to each diversion.

It is important to note that the original plans called for rectangular weirs to be placed below each headgate at all diversion points and that during the first years of operation the water was metered by them. Their use, however, has been discarded in favor of the methods above outlined. This was done because of inaccuracies inherent in the construction of the weirs and the

basins above them. In other words, the plan of measurement by weirs was not brought by experimentation to a state of practicability, but the scheme was discarded when the first design was found to be faulty.

This was due, in a large measure, to the fact that a great deal of head is lost at each diversion. The sill of all gates is at the level of the bed of the main channel, and the bed of the lateral is also on a level with the bed of the main channel, hence the difference in the water surface levels of the main channel and the distributary is lost at each delivery point. The object of this, of course, was to permit delivery when the water in the main channels was very low, and as there is plenty of fall to the country, the loss is not serious. Nevertheless, this fact mitigated greatly against the use of weirs. The water came into the lateral with such velocity that it could not be stilled properly for weir measurement, because the basins above the weirs could not be made large enough to absorb all of the disturbances of the water.

This same fact, however, made possible the scheme of metering the water by considering the gates as orifices, because the flow was always free below the gates, that is, the gates were never submerged. Such a plan with submerged gates would be utterly impracticable.

The formulae by which the flow in these gates is calculated are as follows:

$$Q = (0.615\ a\ b\ \sqrt{2gh})\ 1.035$$

for vertical gates, and

$$Q = \left((0.615\ a\ b\ \sqrt{2gh})\ 1.035\right)\ 1.14$$

for inclined gates.

In these,

Q = the flow,

a = the opening of the gate,

b = the width of the gate,

0.615 = a coefficient of reduction from theoretical to practical,

1.035 = a coefficient used because the bottom contraction of the orifice was suppressed,

1.14 = a coefficient to correct for the inclination of the orifice on an angle of 45 degrees.

The coefficients above given were reported to have been determined upon only after a great deal of experimentation and actual measurements.

It is not likely that a degree of accuracy giving results nearer than 10 or 15% can be expected from this method, and in individual cases the error may amount to 100%. Yet it is probably the most practical plan that could have been adopted under the circumstances, keeping in mind that during the early years of the project there has been ample water for those under the system, and that the expense of ultra-refined results was not warranted.

In later years, however, when the capacity of the system is being taxed to its utmost to supply the demands upon it, when every source of waste and every excess delivery must be guarded against, more refined results will be demanded. They can then be secured easily enough, with a corresponding increase in the cost of obtaining them that will be fully justified.

The use of the current meter is practically unknown in Spain. Measurements of discharge have been made by means of floats, but the generally accepted plan has been to calculate the discharge of both natural and artificial channels by the use of some standard slope formula, after choosing the coefficients that enter therein.

Charges for the Use of Water.

The amount of water in the system has been fixed by law at 0.33 liter per second for each hectare under the system; (1 sec.-ft. for each 213 acres); that is, the canal has a concession from the Spanish Government, giving it the right to divert from the river that amount of water.

The delivery of water, however, is not limited to this quantity. In fact, the minimum for which delivery will be made is 4000 cubic meters per hectare per year, equivalent to a depth of 0.40 meters over the land. This only means that lands that have subscribed under the system must pay for at least that quantity of water, whether it is used or not.

At the beginning of the irrigation season, schedules of the water that will be required by each Association are made out as a guide. These may be varied as the season progresses, but they serve as guides for the amount of water that will have to be carried in the main arteries.

The allowance of 0.33 liter per second per hectare, if evenly distributed over the system, would not always be sufficient. In a season of 200 days, this would correspond to a depth of 0.58 meter, an abundance for olives and vineyards, but insufficient for alfalfa and truck gardening. When, however, the probable division of crops is taken into consideration, the total quantity is probably ample, although less than is generally considered necessary in the United States.

In following the schedules, therefore, it is only necessary to carry in the main arteries the legal quantity. The smaller laterals, however, must have capacity for larger quantities, because of the unequal distribution of crops and the necessity for rotation of water.

An Association can ask for any amount of water, and this amount will be delivered and charged for, provided it can be delivered without danger to the system or causing a shortage to others. Three days' notice is required before deliveries are made.

Each Association is required to pay in advance, at the beginning of the season, the amount corresponding to the schedule as submitted by the Association. At the end of the year, the accounts are liquidated, and any balance is returned or credited on the ensuing year. Whenever deliveries are made to an Association, the amount corresponding to the water delivered is charged against the amount deposited by the Association.

No Association can be formed representing less than 100 hectares, or if formed, it is obliged to pay for water for that number of hectares. No Association can pass water on to another Association.

The Associations, in turn, are obliged to deal with each farmer in practically the same way as the administration of the canal deals with them.

The prices charged for water are set forth in the following table: (These prices were fixed in the concession of the canal.)

Prices in Cents for 1000 Cubic Meters of Water.

Section of Canal	1910	1911	1912	1913	1914	1915	1916	1917	1918
9, 8 and 7	4	5	6	8	10	10	10	10	10
6 and 5	5	6	8	10	10	10	10	10	10
4 and 3	6	8	10	10	10	10	10	10	20
2	8	10	10	10	10	10	10	20	20
1	10	10	10	10	10	10	20	20	20

The sections of the canal are certain zones; the more remote ones, being subject to inconveniences and uncertainties, are allowed a differential in their favor.

After the first of January, 1919, the price will be 20 cents for each 1000 cubic meters for all sections, equivalent to 25 cents per acre-foot.

In addition to the foregoing schedule of prices there is an annual charge of 4.00 pesetas per hectare ($0.30 per acre) for water rights. This flat charge, together with the payments for water as given in the foregoing tabulation, represents the total direct charges made against the water users under the system. Compared with charges levied under both private and public irrigation systems in the United States, this is very low indeed.

The charges for water are intended to cover the cost of maintenance and operation only. The Government is apparently satisfied with the returns from increased value of the irrigated district to compensate it for the original appropriations made for construction of the works.

The first appropriation made by the Government from public funds was for 32,000,000 pesetas ($5,800,000), which was made available at 1½ million pesetas per year. This allotment was later increased to 3 million and still later to 4 million pesetas annually, until the entire amount had been expended.

Construction began in 1896 and was completed in 1909 at a cost of 31,980,000 pesetas, of which 18,000,000 was expended for labor and the remainder for materials, etc.

In order to provide for operation and maintenance during the early years and to make certain improvements, including lining of canals, an additional appropriation of 8,000,000 pesetas was made available at the rate of 1,220,000 per year, 450,000 of which is for maintenance and operation. The total cost of the system, therefore, will be 40,000,000 pesetas, or 380 pesetas per hectare, considering the total area at 105,000 hectares ($28.00 per acre).

Following is a statement, furnished by the director of the canal, of the manner in which the Government expects to be reimbursed for this outlay:

Water right charges 105,000 acres @ 4.00	420,000	pesetas
Increase in taxes due to increased productivity of the lands irrigated @ 14.00	1,470,000	"
Taxes on sugar, alcohol, transmission of goods, and special documents	141,307	"
Poll taxes due to increased population	100,000	"
Produce from olives, figs, etc., along rights of way of canal—500,000 trees @ 0.30	150,000	"
Sale of waterpower—13,700 h.p. @ 100.00	1,370,000	"
Total	3,605,307	"

From this amount is to be deducted the 450,000 appropriated for maintenance and operation, leaving an annual income of 3,155,307 pesetas, which is calculated to liquidate the total appropriations made by the Government in 13 years.

In subscribing lands under the system, or "signing up", regard is had for the crops that will, in all likelihood, be planted, and a certain amount of water is subscribed for. If, during the season, it is found necessary to ask for more water than that named in the schedule submitted at the beginning of the season, the extra amount is delivered, but is charged for at double the price given in the table above.

Unsubscribed lands may secure water at four times the prices given in the above table.

The writer has outlined at some length the practices under the Aragon canal, because here seems to have been made an effort to place an irrigation project on a sound basis. We are liable to think that Spain is somewhat behind other civilized countries in the matter of internal development, yet we must acknowledge that in the matter of modern irrigation practice her methods, as in force on the Aragon canal, are a long way in advance of practice in our own country.

Spain appears to have successfully put into practice the plan that must in time come into general use in the United States; viz., that of selling water by quantity, giving the farmer all he wants, and charging him for what he consumes. It is the only rational method, but we have been very slow to adopt it in this country.

The writer, in conclusion, wishes to extend to Sr. D. Alfonso Benavent, Director, Canal de Aragon y Cataluna, his thanks and

appreciation for the delightful manner in which every opportunity was afforded him to study the system, during the brief period he was able to spend on this project.

DISCUSSION

Mr. Muckleston.

Mr. H. B. Muckleston,* M. Am. Soc. C. E. (by letter), stated that the author gives in his paper an extremely valuable lesson in the preparation of irrigation projects. The paper describes two projects—one of them designed and built without sufficient surveys and advance information, and the other thoroughly investigated and surveyed before design and construction were begun. It is no wonder that the first project is a failure and the second is a success.

In its lessons to the operating official, the contract is equally valuable. The division of responsibility between the canal organization, the associations and the individuals on the Aragon system is ideal, though it may be doubted whether such a division always is practicable under American (including Canadian) conditions. There is one feature of the organization found to be of great benefit in India and which might be workable in America, and that is the practice of giving police powers to certain officers. Most canal superintendents can remember numberless instances when the possession of police powers by their officers would have been of immense assistance in carrying out their work.

The method used on the Aragon system of paying for the water undoubtedly is the ideal one, and it is satisfactory to note that a certain quantity of water must be paid for whether used or not. This is an equivalent of the stand-by or ready-to-serve charge which is familiar in power contracts. The use of that method in irrigation work is followed almost invariably by a decided increase in the duty of water and by far better agriculture on the part of the farmers. The general adoption in America of this method of charging for water is greatly to be desired, but unfortunately the great majority of water contracts now in force make it impossible, except with the consent of the farmers; and the natural conservativeness of farmers as a class most certainly would make them view with much suspicion any suggestion from the water company leading toward such a change in charges. If the change in the method of charging for water does come about, it can be only through suggestions from the farmers themselves and through their own organization, and much quiet missionary work will have to be done before such a result can be hoped for.

The above observations apply to the constructed and settled projects. There are still some projects unbuilt and unsettled where the opportunity exists to put these principles in practice and it is to be hoped that they will be given serious consideration while the choice is still open.

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Paper No. 46

PRESENT CONDITION OF IRRIGATION IN ARGENTINA.

By

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INTRODUCTORY.

In a country which extends from the 22d to the 56th parallel of latitude and between the 53d and 73d meridians of longitude, with wide extended plains which gradually rise from the Atlantic coast to the range of the Andes Mountains with altitudes of more than 7000 m. (23,000 feet), the great diversity of climate and soil stimulates the greatest multiplicity of districts for specific intensive agricultural operations, with their traditions, uses and ancient customs antedating the conquest and in which the Spanish themselves, coming on their part from the provinces in which there prevailed ancient local and peculiar customs, have wrought adaptations more or less governed by their own ideas, but respecting existing conditions, thus giving rise to the formation of extremely variable systems in the treatment of water for irrigation, more or less well established in regulations and ordinances or local laws and rural codes later, all of which make manifest the great diversity of determining factors in the problem.

In a volume of publications of the International American Scientific Congress, held in this Capital (Buenos Aires) during the celebration of the "Centenary", we have reproduced the greater part of these early historical developments, which, for any one province such as Tucuman, were developed in detail with a study of irrigation through the ages from the foundation of the Capital to our own days.*

This diversity of method is moreover fundamental. The

* "Irrigation in Tucuman Through the Ages, 1686-1897".

regional industries, determined by local climatic conditions, have developed extremely diverse systems for the intensive application of water. Private enterprise; coöperative action; official control, partial or complete, are forms all used throughout the country with varying results.

In accordance with the syllabus furnished by the Committee on Publications of the Congress and in order to treat broadly the problem of irrigation in Argentina, we shall pass in rapid review the various features which it presents in its relations with our country.

METHODS OF CONTROL.

Irrigation by private enterprise has especially developed in Tucuman, where the characteristics of the sugar industry have determined this as the preponderant form of development for irrigation works, regarding which ample details will be found in a paper entitled "Zonas de Regadio" which was prepared for the Latin American Scientific Congress, held at Rio de Janeiro in 1905. This industry (the chief one of the province) requires a large capital for the establishment of the necessary plant. In the beginning the raw material must be produced by the manufacturer himself, who is thus cane producer at the same time, that is to say, agriculturist.

More recently, in later years, the manufacturer added to his own raw material that of certain neighboring industries. The canals created by private initiative were transformed into a collective system, but under a measure of influence by the first owner.

The abuses which developed as a result of these procedures determined official intervention, dictating the law of irrigation which today has caused most of these private irrigation enterprises to disappear, determining a coöperative management, controlled by an autonomous and independent authority under the form of law, but with an intervention of the government sufficiently decisive, even to the present time.

The form of operation frankly coöperative has been developed particularly in Mendoza, where the wine grape industry has required an extreme subdivision of the property, in which each viticulturist may with reduced capital make of himself either

manufacturer or grape culturist, distributing and subdividing more effectively the activities of the work. A winery demands but small capital, while a sugar factory requires large sums.

The creation of irrigation canals, being impracticable for each piece of small separate property, has required coöperative action which has developed a marked spirit of association in matters of irrigation, which concerns itself not only with the building of canals but also with their maintenance. In this province, as in that of San Juan, or rather in all those of the Andean region, there has been marked increase in these irrigation communities, which exist also in the Republic of Chile, under the name of Syndicates of Irrigation Communities.

This coöperative system was that originally most generally employed in the country. It has created manifold districts with a laborious and meritorious population deeply attached to the country, with irrigation methods flourishing though primitive and crude, but which have not served to create wealth sufficient to permit the projection and construction of works of the necessary magnitude required for the extension of the original undertakings.

If both systems have given their best results, each within the district of its adaptation, the increase of the zones to be irrigated, the scarcity of available water, the heterogeneity of the population of irrigators, the growing subdivision of the properties, and various other secondary causes have brought about the official intervention of the Administration, in each case more effective, and which today, especially in Mendoza, constitutes a mixed system with all the inconveniences of indefinite, artificial combinations.

This is the manner in which the partial or mixed official control is extended, each time further, and always under the pretext of a pecuniary aid by the government of the provinces or of the nation, abolishing traditional customs, worthy in more than one respect, ancient usages and methods in the management of important common interests, which then with great difficulty the administration can reëstablish, and which notwithstanding, constitute the very foundation principles of a good administration of irrigation.

Complete official control prevails in certain districts of San

Luis and Córdoba, and is extended to various projects on the Rio Negro, with deplorable economic results. Certain districts were created from the beginning and others by the aggregation of existing districts, under the pretext of protection by way of pecuniary aid in order to defend an undertaking in danger, assure an enlargement, or construct a network of distribution canals.

Argentina is relatively poor in available waters, and of those which nature has provided, very few are employed to the best advantage. From this develop two fundamental factors in the solution of the problem of irrigation from the viewpoint of official action.

This intervention comes gradually, because in general it is not an attractive or impressive action to improve existing districts of reduced area and small population; it is without doubt the most profitable method for the interests of the country, because they are centers of activity, of culture, of intensive labor and large cultivation, difficult to create and improvise in perfected form, but easy to develop when the initial nucleus exists and prospers. The decisive influence of this aid would be complete if the administration, instead of displacing the local authorities of irrigation, would limit itself to the construction of the necessary works, supplying pecuniary aid, but respecting the established usages and customs, and utilizing rather the opportunity of its intervention in order to extirpate any practices contrary to our civil legislation regarding water, indisputably superior to other forms as we shall see at a later point.

The most significant official action, and that which absorbs the most capital, consists in the creation of manifold totally new improvements in desert and abandoned regions, in the most divergent parts of the country and always on the basis of irrigating many hundreds of thousands of hectares* with works great in cost and in dimensions.

Within the existing great irrigation districts, as those of Tucuman and Mendoza, the growing development of cultivation calls for works of amplification and the improvement of existing conditions in order to obtain an intensive and rational application of the available water supply. But notwithstanding the fact

* The hectare = 2.47 acres.

that these undertakings are as important as those others, the authorities are attracted rather to the creation of new centers instead of assisting the existing, forgetting that in the matter of irrigation, the technical question is secondary and that social and economical questions must receive first consideration in order to assure a favorable outcome from the first.

Public opinion allows itself to be impressed by the promise of works which give occasion for the marvels which are told regarding artificial irrigation. Railway companies are concerned with the creation of centers of intensive production within their respective zones of influence and, moved by a criterion, comprehensible to simple merchants, which in fact they are, they have offered to the government the necessary means for these great works, under the condition of carrying them out by themselves, with the infantile pretext of doing them with no profit whatever. The government appears to believe them; and in the meantime more than 70 millions of pesos ($67,000,000) are involved in the undertaking of placing 550,000 hectares of land on the market, with a unit cost, with regard to irrigation, so large as to make them little less than unattainable for such occasional purchasers as there are, who would always prefer to seek lands lying within the established districts because they offer many advantages and indisputable acquired experiences, with costs more reduced by reason of dealing with less pretentious and monumental undertakings.

Here is not the place to examine if the land, desert by reason of lack of irrigation, should be valued in proportion to the products which may be drawn from it. In a country with sparse population, like this, in which the demand for land for irrigation is very limited for the reason that there is still much land disposable in which dry cultivation is possible and with less cost and in less time, it is logical that one should seek cheaper land, especially when found within densely populated districts full of resources, with well assured markets, etc.

The State, without need, has compromised immense capital, which will burden the country for a long time, unproductive and prematurely invested, and of which the interest and amortization will weigh on the national economy without any immediate benefit.

In the first works (unfortunately those of lesser importance) official action is profitable and salutary. In the second it is prejudicial and inopportune.

IRRIGATION ALLOWANCES.

The most complete anarchy prevails in regard to the unit allowance of water necessary for irrigation. The diversity of local conditions renders impossible a uniformity of rule throughout the country; but instead of proceeding to the direct experimental determination of this factor, it is preferred to proceed everywhere by groping.

The provincial laws—contradicting in this matter the national legislation, which is obligatory by the National Constitution, and to the mandates of which they owe esteem and respect—have established unit allowances extremely variable, generally high, as much as 2 liters per second per hectare (0.0286 cu. ft. per sec. per acre), as in Santiago del Estero.

The governments, by the indifference and indolence of their technical officers, make no effort to study those questions of such great importance for the economic aspect of their projects, and there is in the country only one experiment station, founded in 1906 by our insistent initiative in Carmen de Patagones, in the Province of Buenos Aires, where incomplete studies have been made of the question, reaching after many years, the conclusion that maximum products are realized with an irrigation of 0.25 liter per second per hectare (0.0036 cu. ft. per sec. per acre), notwithstanding the dry climate found in a region in which the rainfall does not exceed 200 millimeters (8 inches) per year.*

These investigations are continued to the present time and have determined the creation of various districts of intensive cultivation in the vicinity, all with private initiative, and in which the recommended allowance has given entirely satisfactory results.

The official allowances prescribed by the provincial laws exceed the capacity of existing works. In the cane fields of Tucuman, where the legal allowance is 0.50 liter per second per hectare (0.0072 cu. ft. per sec. per acre), I have found personally the

* "Utilization of the Waters of the Rio Negro", by C. Wauters.

opportunity to prove that the planter begged as a favor that the allowance of water should be decreased from the moment that the allowances fixed by the law were promulgated. These are erroneous ideas which it is desirable to remove, basing the reform on the results of a direct experimentation, established in the principal districts of intensive cultivation of the country, remembering that these high allowances were established without extended examination, and in accordance with the relative abundance of water in the rivers for the cultivated zones at the time of passing the ordinances or laws, and which the gradual extension of the same has proven inadequate; taking the case of Mendoza for example, in nearly all the rivers of which there are a greater number of concessions granted, and more water under lien, than can be provided by the gauged stream-flow.

I shall make no mention of the great inconveniences caused by the lack of knowledge of this fundamental factor in irrigation, since its influence is manifold here as everywhere, stimulating the construction of works beyond all proportion, causing erroneous economic situations, increasing uselessly the cost of irrigation, changing the financial aspect of the projects and creating systems of works needlessly expensive.

India, California and all zones of long established intensive cultivation know well the inconveniences of high unit allowances.

REGULATION.

For the entire country the regulation of the water is characterized by an irregularity very marked within limits numerically variable. For nearly all the rivers whose waters are used for irrigation, there is a critical period of minimum flow, at the beginning of spring, which coincides with the most necessary and indispensable irrigation. These are the times in which the good results of a careful organization of the distribution are most evident and in which the benefits of engineering work scientifically carried out are most fully realized.

In the great industrial centers of Tucuman and Mendoza, increase in the cultivated districts encounters a marked limitation in these critical periods, especially in the first named, where the distribution has been developed to the point of admitting no

further appropriation from the small flow disposable. In consequence of this, some ten years or more ago, they assumed the construction of a dam and storage reservoir which we designed in El Cadillal, with a reserve of two hundred million cubic meters of water (162,000 acre-feet).

Once initiated, the construction was interrupted by political and economic causes, and though resumed again years later, it has not yet reached the point of completion of so important a work.

In the second district, Mendoza, the improvement of the conditions of distribution may secure a utilization of the water more rational than today. The construction of storage works, furthermore, is not so necessary.

But although much has been accomplished under the administration of the streams in the irrigation districts formed under private or coöperative initiative, transformed later by partial official intervention, it is not the same with those which the State has created of a single piece. In these, for the most part still under construction at the present day, the storage works are carried on at even pace with the distribution system, creating everything. The province of Córdoba, since 1890, did the same with the only storage dam which exists today in the country of San Roque, on the River Primero, giving a concrete example of resulting economic evil and of slow progress in the development of cultivation; it is true that everything was produced from nothing and likewise the population of irrigators was developed in an elevated zone in the environs of the capital of the state.

There is no doubt that an intermediate solution will be found for the future in the formation of entirely new districts. This will involve the design as a whole of the entire necessary system, even to its ultimate developments, with the first construction restricted to the most indispensable and least expensive works, those which will be sufficient to stimulate the first improvements and cultivations, which with the action of time will establish a population practised in the management and utilization of water and which will gradually develop, and by its prosperity and wealth will undertake later the completion of the works, when they can be amortized and preserved suitably by a population interested in its future.

A population of little more than 3 inhabitants per square kilometer (7.8 per square mile) does not permit the expectation of a large demand for irrigated lands, costly and exacting, where agricultural credit is established by labors of rapid return rather than by waiting four or five years to receive the first fruits, as with intensive cultivation.

UNDERGROUND WATER.

These same general considerations bring into strong relief the immense natural resources which this country offers for agricultural operations. It is understood, furthermore, that there has been no thought of utilizing underground waters for irrigated land, since there is still an abundance of land, in suitable latitude and with favorable climate, where irrigation may be realized with surface waters.

Borings or soundings have been made on a reduced scale in proportion to the extension of the territory, but for the most part in order to assure potable water for the use of centers of population, founded for reasons of various kinds. In many cases good results have been realized, water-bearing strata being generally found in the Argentinian subsoil, without to this time going much further, in their detailed study.

In other cases, these investigations have given unexpected results, as with the discovery of immense oil-bearing lands in Comodoro Rivadavia, on the Patagonian coast, which was repeated in the vicinity of Bahia Blanca, the great military port of the South.

For Argentina, the time has not yet come to consider the development of the subsoil waters for purposes of irrigation. There is still an abundant supply of surface waters.

DEVELOPMENT OF PUBLIC CONTROL.

The apparent indolence in the matter of irrigation in this country is thus explained. Until 1900, the Nation had not spent much more than a million pesos ($960,000) on irrigation works, while it had already invested more than a thousand millions ($960,000,000) on various public works. There had been divided

in eight principal groups not more than 650,000 irrigated hectares (1,605,500 acres), for the most part by private initiative or coöperative undertaking.

The provinces which most suffered the need of irrigation did not succeed in awakening the interest of the Nation to grant them pecuniary assistance. The most wealthy and prosperous prepared plans for works of scientific improvement, but could not finance them at a suitable time.

The Nation which had remained indifferent for so many years, proposed, through a law well intended but with little foresight, to take up all the rivers of the country, transform them in a few years and inundate the market with irrigable land, in all parts of the country, without stopping to consider the enormity of the expense imposed on a people which was not prepared to make of themselves over night such optimistic partisans of irrigation and its marvels.

It is not strange, therefore, that in this country there appear anomalies in the matter of irrigation, in the systems of distribution, plans of works, ordinances and laws, administrations and exercise of authority, of extremely variable technical value—for the most part a product of hasty action, signalized from the highest directive positions as a banner of patriotic action.

But the reaction will come. Legal administration of water supply is best in principle; the only error is in its application, giving exaggerated importance to the question of technical hydraulics and thereby omitting the predominant factors in every irrigation undertaking: the legal administrative aspect and that of the economical financial character.

Thus, for example, in the matter of a system of distribution, the method imposed by the general law establishes that the State has absolute control over the waters of the rivers, which are considered as part of the public domain, and that they may be granted to individuals for various purposes, domestic use in haciendas, industrial uses, irrigation or power, but not in fee simple, but rather the use and enjoyment alone; and in order that this can not be interpreted as executed to perpetuity, which would amount to the same thing as alienation, the civil law, correctly interpreted, fixes a term to this concession—thirty years in new projects such as that which is now in hand for the Prov-

ince of Buenos Aires—renewable for as many equal periods as the owner may manifest a desire to continue enjoying the benefit of his concession.

It has been well established, as a consequence of this same fundamental concept, that the concession does not carry the obligation of recognizing a fixed and determinate flow of water, or otherwise a specified unit appropriation. The concession implies the recognition of the right to use water for irrigation, for example, in the quantity necessary for the degree of cultivation freely elected by the proprietor, but in the quantity and form which the administration may consider most appropriate for the general interests of the neighborhood.

This principle laid down by the Civil Code of Argentina has not always been respected by the provincial laws, which have adopted traditions of Spanish origin, which although recognising the dominion of the State, establish a distribution proportional to the available water; in others they assign a fixed flow for each concession, all according to the origin of the founding villages and the greater or lesser influence of the inhabitants in matters of irrigation.

Even more, the decimal metric system is obligatory in the country; and notwithstanding this, in some of these laws, measures are specified, clearly Spanish in their names although changed in their intrinsic value, as a result of the diversity in the conditions of application which are made in the effort to correctly interpret such matters by village authorities, more or less ignorant in technical equivalents and in hydraulic principles. In the center served by the San Roque reservoir, in the hills of Córdoba, the civil law itself has been changed by the local authorities, considering that the concession implies the obligation on the part of the administration to deliver a total annual volume of water per hectare, distributed in as many irrigation units as may be considered suitable by the administration, which consults those interested in the matter.

PAYMENTS AND TAXATION.

The control in the use of water is little less than impossible when there is no distribution system scientifically carried out.

Where there are such, the administration does not use them with this object; and if there exist measuring appliances, generally trapezoidal weirs with free fall, they are scarcely suitable, since these weirs, used in clear and tranquil waters with good results, can not be expected to give the same results in rivers with very different conditions.

The taxes are especially variable, but in the greater part of the country are established per hectare irrigated, because, moreover, the greater part of the concessions are administered on the basis of this unit. In the most perfected systems of distribution, the taxes are of varying classes: a unit annual contribution is destined to the amortization of the works constructed by the State; a tax contributes to the payment of the personnel which forms the administration; a third quota serves to pay the expenses of upkeep of the works.

In some regions the system has been simplified, by collecting a single irrigation fee which comprises the various parts enumerated. In others there is found the system of payments or contributions in farm products and in days labor, established in proportion to the interest of each owner.

RECOMMENDATIONS OF INTERNATIONAL COLONIAL CONGRESS.

The indifference and indolence with which matters related to irrigation are treated are not peculiar to Argentina. It is much the same throughout all the Latin American countries; and without fear of contradiction, we may affirm that the greatest extension of land irrigated artificially corresponds to our country, which counts, furthermore, the greatest number of irrigation works in order to assure this irrigation, and with the greater appropriations for upkeep.

The contrast with the conditions in other countries is suggestive. Since 1884, there has met in Brussels and elsewhere an International Colonial Congress, in which the European countries which are occupied with colonial expansion are represented, in order to discuss the various questions relating to the different systems of government of their colonies, of their legislation, their wealth, their economic and commercial administration, etc. In the seventh session, held at London in 1903, it was resolved to

incorporate in the deliberations of the following session the subject "Different Systems of Irrigation in the Colonies".

Following this, in three successive sessions, held at Wiesbaden in 1904, at Rome in 1905, and at Brussels in 1907, there was demonstrated a great interest in this question of live import for colonization, which provoked full discussion, and gave occasion to the publication of very interesting documents, also to the preparation of papers incorporated with the proceedings and to three large volumes especially devoted to the different systems of irrigation, which comprise documents, laws and regulations from India, Canada, British Columbia, United States of North America and Spain.

In the last of these sessions it appeared that certain reports on irrigation had been requested from Peru and Chile, but that those sent were so deficient that they could not serve as a basis for serious study. At the same session it appeared that request had been made of both countries for papers on irrigation and its historical antecedents, which to this time had not been furnished.

To return to the proceedings of the sessions and their various publications, it may be noted that Latin America has not occupied the attention of the different meetings. Certainly reference was made to Peru and to Chile, but in order to lay upon them the charge of indifference which we have noted. As to Argentina, it scarcely appears to exist for the great Congress and its illustrious members, with its great power of assimilation for European immigration and with climatic conditions, for most of its territory, greatly superior for colonization to those of the greater part of the colonies of the countries represented at the meetings. These facts apparently have not been a sufficient reason for them to remember that this great country, endowed by Nature with the most important river systems, should have had occasion to occupy itself with the artificial irrigation of its lands, and might therefore have laws and regulations which would offer material for study to these savants, who, before formulating a law for the use of their colonies had resolved to publish the original texts of existing legislation, in order to draw therefrom the principal foundations of their own project.

The omission was unfortunate, nevertheless, for this Congress, because there may be found in the legislation relating to

the waters of Argentina all the fundamental bases collected which, in the session at Rome, were considered necessary for a good administration of water supply. Edited by the Engineer, R. A. van Sandick, they were presented by him at this session, but with the request that before discussion a comparative study should be made of existing legislation.

These fundamental principles are the following:

(1) Legislation regarding irrigation, or, rather, regarding water in general, should be essentially distinct in humid and arid countries.

(2) In new or arid regions the doctrine of the common law of riparian rights, which constitutes the basis of the legislation regarding water in many humid regions, is incompatible with the development of irrigation.

(3) In arid regions in which the land is not productive except through the use of water, the water-rights should be inseparable from the right of title to the land on which they depend.

(4) In arid regions, neither priority nor appropriation can fix the limit of right to the use of water. This limitation lies in the productive use of water.

(5) If in an arid country or region it may be foreseen that agriculture will be carried out on a basis of artificial irrigation, its development should not be awaited before legislating in this respect.

(6) In new countries, the central government should preserve dominion over the water for irrigation and control its use, managing its distribution through officials created and recognized by itself.

The legislation regarding water is uniform throughout Argentinian territory, because it is governed by the provisions of the Civil Code, which, in article 2314, provides that water is the public property of the national State and of the individual States, the use and enjoyment of which is held by individuals under control of the provisions of the Civil Code and of the general or local ordinances (articles 2340 and 2341).

This unity of legislation is a great advantage, since practically the provincial laws regarding irrigation have been framed in arid zones alone. Notwithstanding, this general legislation, which compares favorably with those most recommended by juri-

dical sciences and by agricultural experience, has not received equal consideration on the part of the irrigation laws of the provinces. Regarding the latter, a distinguished professor of law, in a study on water legislation published in 1902, inquires whether these irrigation laws, special or integral parts of the rural legislation of the provinces, may not have compromised the unity of the civil legislation, with ill-considered adaptations, inconvenient amplifications and, what is worse, with prescriptions decidedly contrary to those of our national code.

Nevertheless, it is just to recognize that the more recent laws are more and more falling into harmony with this general legislation, because recognition is given to its indisputable advantages, and there are interests tending to remove from these local ordinances, or regulations, the residue of the influence due to ancient vicious practices, whose reason for existence is now disappearing in proportion as the irrigation districts are carrying forward the works required to constitute a complete network of distribution. Furthermore, by mandate of the National Constitution (Art. 31) and of the Civil Code (Art. 2341), all local laws and ordinances must be in conformity with the prescriptions of the code.

The second fundamental principle was likewise clearly recognized in our Civil Code, which in article 2542 provides that "It is forbidden to riparian owners, without a special concession from competent authority, to change the natural course of a stream, to excavate the bed or to withdraw the water in any manner, or in any quantity whatsoever".

In conformity with the text of articles 2340 and 2341, as already noted, the administration alone gives the right to the use and enjoyment of the water, and in such manner that the concessionaire does not acquire any property right in a determinate flow of water, but only the right to use it; so that the concession for irrigation, for example, implies, before everything, the ownership or possession of the land, and to which indeed is granted the concession and which cannot pass from one holding of land to another, even though it may belong to the same owner and be contiguous, etc.

This same principle assures the defaulting of the concession in case of non-use, without any question as to any right to the

priority of use or of appropriation. There is no proof of the exercise of the concession other than the use of the water and the payment of the taxes and dues which are imposed.

From the form of political organization of this country, the central and provincial governments preserve the exclusive control of the public waters, grant concessions and administer them in conformity with local ordinances, which must be in harmony with the provisions of the Civil Code.

It thus results that the legislation regarding water in Argentina, and especially in its applications to irrigation, satisfies clearly and explicitly all the fundamental conditions which the International Colonial Congress considered necessary for good legislation.

We have desired to bring out these points because it is but a further illustration of the fact that many things relative to our country escape notice by the fault of her sons, who are not concerned with making them known in accordance with their merits, and because they may contribute to the solution of many engineering problems of diverse character.

Paper No. 47

DAMS.

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INTRODUCTION.

The remarkable progress of the last few years in the application of science to the uses of man has extended to the design and construction of dams. The wide range of experience covered by recent practice in this branch of engineering affords an extensive field of study and an inexhaustible mine of information.

The progress of sanitary science, demanding better and more generous water supplies for rapidly growing urban population; the wonderful growth of water power development; and the demands of irrigation and flood control have all performed their parts in stimulating the construction of dams of all classes; and the large number of such structures recently built have led to the evolution of ideas and theories that inevitably accompanies important experience. A brief review of the leading developments along these lines may be of interest.

The two great classes of dams are those of masonry and of earth, which, though fulfilling identical functions, are so different in character and construction as to require widely different treatment both in theory and practice. Between these two distinct classes, the rock-fill and the combination of earth and rock-fill constitute a third class partaking more or less of the characteristics of both the main classes.

The subject of dams is so large and the problems presented are so difficult that a paper of this kind must necessarily be confined to a few general aspects. It is proposed to limit its scope to a review of certain tendencies, developed in recent years, to depart from previous practice in regard to design, materials and methods of construction.

Examples will be quoted to illustrate the points raised. If reference is made to dams constructed in America to an extent which may give them undue prominence, the writers offer the apology of greater familiarity with such dams, and wish to express their opinion that other dam construction has kept equally abreast of the times, and the hope that discussion may remedy any lack of balance in this respect.

For a logical treatment of the subject, it seems best to ignore the purpose of the structures. While this may at times exert some influence on design, its effect is generally not of a material character. The more natural division already mentioned refers to the material of construction, generally dictated by considerations of foundation and materials available.

MASONRY DAMS.

Up to 30 years ago, only one general type of masonry design had been carried out in America, namely, mass masonry, depending for stability against water pressure on weight of material.

The most favorable disposition of material was determined upon the assumption that tension in masonry should be avoided, leading to the requirement that at any horizontal plane the resultant of all forces should fall within the middle third. The theoretical section, considering water pressure alone, thus became a rectangular triangle, with its apex at maximum high water level, a vertical water face and a downstream slope of approximately 2 to 3, dependent on the specific gravity of the masonry. This theoretical section was then adjusted to the constructual necessity of providing top width and the limitations assumed for permissible compression stresses in the dam itself and on the foundation. In some cases, ice thrust was assumed in addition to water pressure. Examples of this type of dam are the old and new Croton Dams and the Ashokan

Dam of the New York Water Department, the Wachusetts Dam for the supply of the Metropolitan District, including Boston, the Elephant Butte Dam of the United States Reclamation Service near El Paso, and numerous others. These dams are all intended for water storage and are not subject to overflow, independent spillways being provided to pass flood waters.

The same type, with the addition of an apron, is very commonly used in diversion dams, as in the case of the Granite Reef Dam, near Phoenix, Ariz., the Bull Sluice Dam near Atlanta, Georgia, and especially the La Grange Dam, near Modesto, Calif., the latter having a height of 100 feet. The Boonton Dam, near Jersey City is an example of a dam which for part of its length acts as a spillway.

Mr. John D. Van Buren, in 1895, pointed out the danger of sliding[1] to which dams of this type are subject, if approximately horizontal cleavage planes exist in the masonry itself, or in the foundation. The upward pressures in such planes tend to reduce the pressure of superstructures upon foundation, upon which resistance to sliding is largely dependent. The failure of the dams at Austin, Texas, and at Austin, Penn., illustrates this danger. An increase of section and weight was therefore proposed to meet this danger, the extent of which can be only surmised, as it is dependent on factors difficult or impossible to determine. The San Mateo Dam, near San Francisco, was designed to resist uplift under its entire base, equal to the hydrostatic head, reservoir full.[2]

This involves the assumption that cleavage planes can exist in which there is no point of contact between the over and underlying strata, and yet these bodies are so close together as to confine the leakage and produce full uplift. This condition is, of course, impossible and can hardly be approached in practice. Various compromises have been proposed, all either involving some diminution of pressures near the downstream slope, or making reduction for areas in contact. The Olive Bridge and Kensico Dams of New York City Water Supply were designed on the theory that upward pressures would occur equal to full head of full reservoir on the upstream side, and

[1] Transactions Am. Soc. C. E., Vol. XXXIV, p. 493.

[2] Transactions Am. Soc. C. E., Vol. 75, p. 216, L. J. Leconte, Dec., 1912.

full head of ground water on the downstream side, the head varying uniformly between these limits.[3]

Natural conditions vary widely, but it is not safe to assume any foundation to be entirely impervious. The determination of the perviousness of natural formations is one of the most difficult things in nature. Any examination of such formations which disturbs them, changes the conditions which it is desired to ascertain; for this and other reasons, it is necessary to allow a large factor of safety in any estimates which involve this factor.

In general, it may be said that water will more readily follow seams or bedding planes than devious paths through the material of the rock. It follows that it will pass more readily and in larger volume in the direction of stratification than in a direction normal thereto. Similarly, stratified rock will permit percolation more easily and in greater volume than good massive rock, such as granite.

Granular rock, such as sandstone, is likely to transmit more water through the rock itself than one of denser or finer grain, such as limestone or shale, but no exact rule of this nature can be laid down, because there are many varieties of each kind of rock, with various percolating capacities. In general, however, the following rules may be taken as a rough guide.

1. Massive or crystalline rocks, such as granite, gneiss and schists, will transmit water less freely than those of sedimentary origin.

2. Stratified rocks will transmit water much more readily in the direction of stratification than transversely thereto.

3. In the direction normal to stratification, sandstone will generally transmit water more readily than limestone, and the latter more readily than shale.

4. Stratification on a plane approximately horizontal is the worst possible condition for introducing upward pressures beneath a dam. Conversely, the most favorable position in this respect for stratified rock is in vertical beds.

Avoidance of tensile stresses in the water face of a dam is clearly of the utmost importance in connection with uplift

[3] Transactions Am. Soc. C. E., Vol. 75, p. 170, Chas. E. Gregory, Dec., 1912.

pressures, since cleavage planes might otherwise be formed at the point of greatest danger. Some interesting experiments with small models of dams made of flexible material indicate that even with the resultant falling within the middle third, tensile stresses are liable to exist at the heel of the dam.[4] The existence has also been alleged of severe shear stresses, such as would materially reduce or neutralize supposed factors of safety.

The success, however, of so many of the dams of ordinary gravity type where no distinct cleavage planes exist in the foundation material, makes any large addition to the triangular section seem unwarranted. Moreover, other and more economical means suggest themselves for overcoming danger of sliding, the foremost of which has been the adoption of a plan for the dam curved upstream instead of straight. Each portion of the dam remains self-supporting by its own weight as to horizontal water pressures, while arch or wedge effect will develop in case of tendency to slide. Its application generally involves but a moderate additional mass, where the dam is relatively short. The Furens Dam in France, the Cheesman Dam in Colorado, the Roosevelt Dam in Arizona, the East Park Dam in California, and the Arrowrock Dam in Idaho, illustrate this principle. The Sweetwater Dam in California, as originally completed in 1895, is an example of a dam in which, considered as a gravity dam, the resultant with reservoir full strikes outside the middle third, and in which the arch effect due to its curved plan is depended upon to prevent tension near the water face. It was, however, enlarged in 1911, as a gravity structure.

Uplift pressures being due to penetration of water can be reduced or prevented by increasing the density of the masonry near the water face, by surface treatment of this face, and by deep cut-off and drainage. All these means are now being employed, as, for instance, in the case of the Elephant Butte Dam, New Mexico. The concrete masonry, for a depth of 10 feet from the water face, is extra rich in cement, the face is given a one-inch mortar coat with a cement gun, the cut-off wall at the heel has been carried to a great depth (Max. 100 feet below river water), and the method of grouting under pressure is employed

[4] See Engr. Record, March 6, 1909, Vol. 63, p. 269.

to 50 feet greater depth. Downstream from the plane of closure, drainage wells have been provided in the masonry and drilled in the foundation to dissipate pressure of seepage water. Similar precautions have been taken at the Arrowrock Dam, Idaho, which, moreover, is built on a curved plan.

Another method for reducing uplift pressure is used in the case of low diversion dams built on water-bearing material, as, for instance, the Grand River Diversion Dam, Colorado. This consists of a concrete blanket or apron extending upstream from the heel of the dam, with cut-off wall at upstream edge. The effect of such apron is to lengthen the path of percolating water, thereby reducing the upward pressures under the dam, which, moreover, is given added weight to resist the estimated remaining uplift. The same effect has been aimed at in puddle-fill on the water side, which method appears to have been more common in Europe than in the United States.

It is apparent that the natural process of silting, where water carries silt, will aid in reducing upward pressures, the artificial means, in case of silt-bearing water, being especially intended to obviate danger during the earlier years.

In low dams constructed of wood, it has for a long time been customary to provide a water face with a rather flat slope, resulting in a vertical water load on the foundation which would tend to resist sliding. This type of dam has been copied in reinforced concrete for structures of considerable height. Near Douglas, Wyoming, a reinforced concrete dam of this type has been built for storage purposes, having a total height of 130 feet. A portion of this dam is adapted to overflow as a spillway. A notable overflow dam of this type is the Clackamas Dam, 70 feet high, recently built near Portland, Oregon.

The water slab is supported by buttress walls, which afford a relatively long base up and downstream, imparting great safety against tensile stresses (except in the reinforced slabs themselves), and also rendering it economically practicable to reduce foundation loads either by spreading of the bases of buttress piers or by placing them on a continuous concrete floor. It is essential that such floor be provided with weep holes to eliminate upward pressures.

The low foundation pressures which can thus be eco-

nomically secured render this kind of dam practicable on gravel foundations, provided a deep cut-off connects with the water face slab or the latter be extended upstream in the nature of an apron. Dams of this type have also been built on clay foundation, slight settlement being immaterial in view of possibility of sliding adjustment between abutments and water face slabs.

The facility with which construction of this kind of dam will permit handling of flood flow during construction is obvious and valuable.

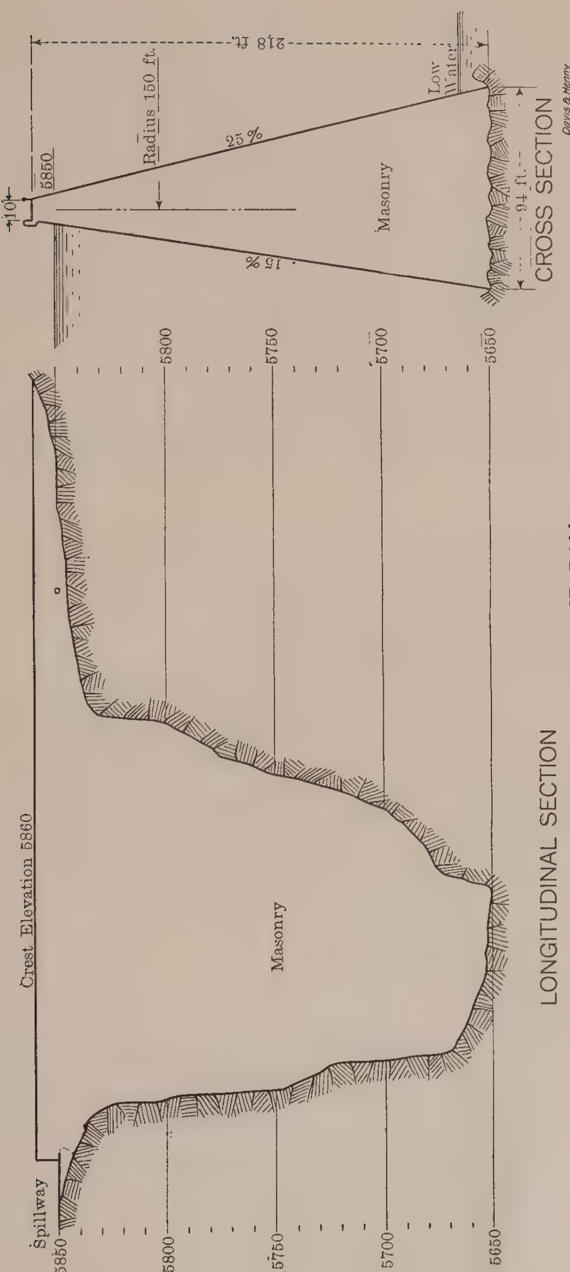
This type of dam has also been executed in steel, as in the cases of the Ash Fork Dam in Arizona, and the Hauser Lake Dam, Montana. The latter dam failed, but its destruction is believed to have been due to insufficient cut-off and piping, part of it having been founded on gravel, and is in no way to be attributed to the substitution of steel for reinforced concrete.

Dams to be constructed in relatively narrow canyons invite consideration of the use of the arch principle, not merely as a safeguard against sliding, but as the chief means of resisting horizontal pressure. The famous old Bear Valley Dam, California, now made useless by the construction of an Eastwood multiple-arch dam a short distance downstream, furnishes the boldest example of this type, in which arch pressures may have existed of over 70 tons per square foot. More recent instances are the Pathfinder Dam, Wyoming, and the Shoshone Dam, Wyoming, of the United States Reclamation Service, the dam near Ithaca, New York, and a number in Australia. The safety of these dams depends upon unyielding abutments and limitation of arch pressures. These pressures generally range between 15 and 30 tons per square foot. Danger from sliding due to upward pressures is absent.[5] The division of load between the arch and the cantilever introduces secondary stresses, the nature of which is as yet not thoroughly understood.

Dams of this type are usually protected from overflow by independent spillways. The Huacal Dam, in Mexico, has but a partial spillway protection and may at times be overtopped, for which reason an auxiliary low dam was built downstream to form a water cushion and protect the foundation.

All the above dams are arched to a radius, which remains

[5] Engr. Record, Oct. 8, 1910, Vol. 62, p. 403.



PATHFINDER DAM

Fig. 1.

constant from foundation to top. Considerations of economy have led to a design with a variable radius and as near as feasible constant circumscribed angles. The principle has been developed by L. R. Jorgensen, M. Am. Soc. C. E., who shows that a considerable saving of masonry may, under favorable circumstances, be effected, and has been applied in the Salmon Creek Dam, Alaska, and the Lake Spalding Dam, California, and on a smaller scale in the Clear Creek Dam, Washington, which latter is also an overflow dam. It may be stated as a matter of historical interest that the original Bear Valley Dam was built with a shorter radius in the lower part than in the upper.

A series of vertical arches supported by buttress walls was used as a low spillway dam in connection with the East Park Reservoir, California, for purposes of economy and lengthened spillway crest.

The principle of the inclined face dam with buttresses has been successfully used recently by substituting arches for flat slabs, resulting in the multiple arch type. This permits avoidance of beam tension in the closing curtain and obviates the necessity of dependence upon concrete embedded steel, the life of which, in saturated concrete, is as yet a matter of uncertainty. A diversion dam of this type was built on the Umatilla River in Oregon, and a storage dam with a maximum height of 61 feet at Hume Lake, California. A singular example of this type of dam occurs on Lost River near Klamath Falls, Oregon, where a plan in the shape of an elongated horseshoe was adopted to give the desired length of overflow so as to avoid submergence of valuable land in times of freshet, and to provide a basin for receiving the overflow water.

Contraction Joints.

The reinforced and multiple arched types naturally contain numerous contraction joints. Such joints were introduced in the Ashokan, East Park, Arrowrock, Elephant Butte, and other gravity dams. Dams of the pure arch type have, however, been generally of monolithic construction, the need of contraction joints being less marked by reason of greater flexibility of the general body. No cracks have been so far observed in the Pathfinder Dam; however the upper 35 ft. of this dam are reinforced

and expansion joints were put in at the abutments. The Shoshone Dam shows a very slight crack near the top at each abutment.

Contraction cracks being objectionable from the standpoint of ultimate life, as well as appearance, many dams are now provided with contraction joints for a part of their height. These are placed from 100 ft. to 50 ft. apart, and near the top sometimes closer. They are provided with one or more keys and at times with a metal water stop, and usually with a drain back of the closure. These joints permit shrinkage due to setting, as well as to temperature effect, and tend to reduce secondary stresses. They do not seem objectionable in any way, except in requiring more form work. The work can be laid out so as to construct the alternate sections, at least near the top, at a time when contraction is at a maximum.

Material.

The material used in masonry dams has been coursed masonry throughout, rubble masonry faced with coursed masonry, using ordinary mortar or concrete mortar in connection with very wide joints, coursed masonry faced with concrete interior, and all concrete with or without plumstones. The use of concrete has been growing in favor. It can be laid mainly by machinery, and is economical in many locations where good rock is not available. The economy of its use has recently become more marked through improved processes of mixing and depositing. It requires, however, more cement than rubble masonry, which, where distance of cement haul is an important factor, may render the latter at times the cheaper.

The New York Board of Water Supply has built two dams of concrete, faced on both sides with concrete blocks laid in mortar. These block faces serve instead of forms, and as they can be cast while foundations are in preparation and in all kinds of weather, they tend to expedite construction. Their chief virtue, however, is their appearance.

Portland cement is now universally used in mortar and concrete and is shipped from commercial mills. The mass concrete is generally proportioned 1:3:6, the aggregates being crushed rock or gravel tested for minimum voids. In some cases Portland cement has been ground locally with sand (sand cement)

in proportions varying from 40% to 50% of the mixture. This material was largely employed on the Arrowrock and Elephant Butte Dams, in order to reduce the proportionate cost of cement. It sets more slowly, however, and forms are therefore more costly per cubic yard, as they cannot be removed as soon as with normal cement concrete. This tends to reduce the saving due to reduction in pure cement. A like result follows from the tendency to increase the proportion of sand cement, as compared with normal Portland cement used in the mixture. There has also been observed greater liability of damage to surfaces from frost, probably due to slow hardening. The tests with concrete blocks show a slightly reduced strength, but indicate no reduction of strength with age and a strength ultimately equal to that of straight Portland cement. It is only on work of great magnitude, where freight items are large, that any saving can result from the use of this material.

The concrete with either Portland or sand cement is usually mixed sloppy, water being carefully limited, however, so as to avoid excess. This consistency permits distribution from towers and through pipes. It is worked by shoveling and man-kneading so as to make it as homogeneous as feasible and to release contained air. Spades are used next to the forms to insure sound and tight surfaces. The tendency to the formation of smooth surfaces between old and new work is counteracted by wire brushing and by imbedding plum-stones.

Cement Made Locally.

It is the universal custom to transport Portland cement to the locality. An interesting exception is the case of the Roosevelt Dam, in Arizona, where the distance from the nearest railroad point was 60 miles, with mountain roads intervening. Suitable materials for manufacturing cement were found near the site and local manufacture caused a saving estimated at over $1,000,000 in the construction of 360,000 cubic yards of masonry.

Spillway Control.

The use of movable dams has been steadily increasing to meet conditions under which it is necessary to maintain a relatively constant water level under fluctuation, flood or changeable uses of water. Devices for such use are very numerous. The various forms of wickets and shutters have been long in

use in Europe and America with a fair degree of success. The more recent bear trap, to be operated by water pressure, has had several modifications and has been frequently employed.

The Stoney sluice gate, gliding on movable rollers to reduce friction, which is employed extensively in the great Assuan Dam of Egypt, has been adopted, with some modification, for the spillway of the Gatun Dam at Panama. It has also been employed in many other cases.

For cases in which long span is essential, the roller dam patented and employed in Europe for some years, has recently been introduced into the United States, the first installation being a small one upon the Boise River in Idaho, and several larger installations are now in progress on the Spokane River, in Washington, and the Grand River in Colorado. This, in addition to the practicability of very long span, has the advantage of simplicity, certainty of action, and a good degree of water-tightness.

To accomplish the same purpose by another method, the siphon spillway has recently been introduced to this country from Europe, and used in several cases with success. Having no moving parts, it is well adapted to certain locations where there are no complications from drift and ice, and where the volume of the fluctuation is moderate. It has the further advantage of being adapted to construction of concrete, and is, therefore, more permanent than steel or wooden structures. By various simple adjustments, a series of such spillways can be so arranged as to prime themselves automatically at different levels and thus secure any desired gradation in rate of discharge.

EARTH DAMS.

The construction of this type of dam reaches back into earliest antiquity, beginning probably as earthen dikes, to prevent inundation, and extended in this form to all parts of the world. It is illustrated also by hundreds of dams of considerable height in India and elsewhere, many of which are very old.

The design of earth dams is not subject to mathematical analysis. It must of necessity be based on the application of general experience. This type of dam, being the result of slow

evolution, the experience of recent years has been able to add relatively little to known facts, and any considerable departure from previous practice is mainly in the methods of handling. The magnitude of structures of this class has, however, greatly increased. General requirements are somewhat better understood, while new methods of handling materials have had their effect upon design.

The original scientific conception of an earth dam probably was a mass of material compacted so as to be water-tight throughout, connecting with a tight substratum and disposed to slopes somewhat flatter than the angle of repose. Extensive cores of puddle or heavy walls of masonry were used in the center of the structure when doubt existed as to the water-tightness of the general mass.

The use of a clay puddle core, with a dam of material more or less open to percolation, has become less frequent than heretofore in ordinary dam construction, while the heavy masonry core, common in early Eastern dams, has been greatly reduced in dimensions and has been made less rigid as a diaphragm through the use of reinforced concrete. Where a core is used, it is frequently carried up to only partial height so as to break the path of the water trying to percolate under the base of the dam.

The character of puddle now deemed safest by most engineers is not pure clay, but a mixture of gravel, sand and clay well blended and compacted by a heavy roller, with a small admixture of water. This material is less liable to cracking and slipping than pure clay and absorbs less water. There is, moreover, a greater tendency, where only a portion of the dam is tight, to place this portion as close as practicable to the water face, thereby increasing the backing which supports it; also to employ coarser material for the downstream portion of the dam, for greater stability and better drainage. Hundreds of earth dams have been built within the last two decades under a wide variety of conditions. As failures of earth dams have been generally due to overtopping, to piping under the foundation or along outlet conduits, or to sloughing, special attention has been paid to safeguards against such accidents.

In regard to overtopping, protective measures have con-

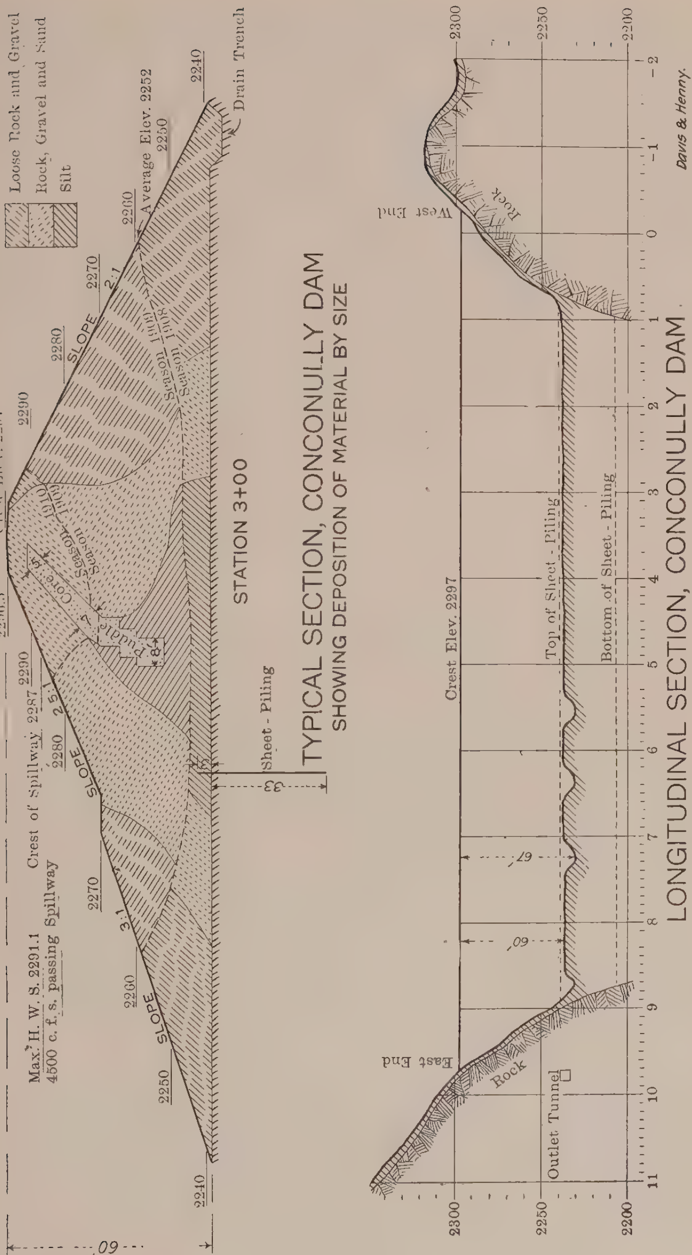

Loose Rock and Gravel
Rock, Gravel and Sand
Silt
Max.? H. W. S. 2291.1
4500 c. f. s. passing Spillway
Crest of Spillway 2287
Crest Elev. 2297
2296.5
Average Elev. 2252
Drain Trench
SLOPE
Core
Puddle
Season 1909
Season 1908
Season 1910
Season 1909
Sheet - Piling
STATION 3+00
TYPICAL SECTION, CONCONULLY DAM
SHOWING DEPOSITION OF MATERIAL BY SIZE
West End
East End
Rock
Crest Elev. 2297
Top of Sheet - Piling
Bottom of Sheet - Piling
Outlet Tunnel
LONGITUDINAL SECTION, CONCONULLY DAM
Davis & Henny.

Fig. 2.

sisted of close study of possible flood flow and provision of ample spillway capacity and freeboard. Piping under the foundation, which may occur where connection cannot be made with a tight substratum, is guarded against by lengthening the path of the water through slope flattening, by deep puddle-filled cut-off trenches, sheet piling, as in the case of the Conconully (Wash.) Dam, and sometimes all these means are used, as in the Wachusetts Dike. Grouting was used in connection with a deep cut-off wall in the case of the Lahontan Dam, which is built mostly on mudstone in which many fissures occur. Piping along outlet conduits is prevented by construction on unyielding foundation and by frequent and large cut-off collars. Sloughing is prevented by the use of masses of open drain material in the downstream body of the dam, by drainage pipes, or, as in the case of the Belle Fourche Dam, partially by above methods as well as by extreme care in construction, through limiting water contents and hard rolling with traction engines. In the latter case, it is believed that the clay was rolled into such a compact and rubbery mass as to prevent the penetration of water other than by capillary action.

More scientific processes have been employed lately in the determination of rates of percolation which would take place through materials at hand for dam construction, made necessary, especially in the West, because of general sandiness of surface material. It was found, as in the case of the Cold Springs Dam and, subsequently, in the case of the Lahontan Dam, that mixtures of available materials could be used which gave rates of percolation about one ninth that of the tightest material at hand, if used by itself.[6] Thus, it has been economically possible to construct practically tight dams with sandy material. In such cases, mixtures have been graduated so as to increase in perviousness away from the water face, to secure perfect drainage.

In one important case (the Standley Lake Dam in Colorado), conservative methods of earth dam construction have been deviated from by omitting sprinkling and rolling and by loose dumping the clayey materials from trestles. The results have been unsatisfactory, as might have been surmised, in caus-

[6] Transactions Am. Soc. C. E., Vol. 74, p. 43.

ing over 10% of settlement in the height of the structure with water about two thirds of its intended height, accompanied by bulging, cracking and some leakage, causing fear as to the safety of the structure and resulting in an order from the authorities to reduce the height of water in the reservoir.

Slopes of earth dams are generally 3 to 1 on the water face, and 2 to 1 on the dry face, although steeper slopes have been successfully used, as in the case of the Belle Fourche Dam, where they are 5 to 1 for a short distance, then 2 to 1 and 1½ to 1 on the water face and 2 to 1, with two 8-foot berms, on the dry face.

In the compacting of the earthy portions of dams, there has been a tendency to thin layers (6″) and to the use of heavy rollers 10 to 30 tons, or preferably traction engines, as giving great concentration of loads and avoiding continuous jointing planes.

The most radical departure from former methods of dam construction has been the occasional adoption of the hydraulic method of conveyance and deposition, on works of the greatest magnitude, such as the Gatun and Necaxa Dams, and the Calaveras Dam in California, now under construction, also on smaller works such as the Conconully Dam. The use of this process, and the consequent results, constitute perhaps the most interesting chapter in the recent history of dam construction. The interest attaches to this process, not only as a measure of economy in construction, but still more because of the results obtainable from the skillful employment of the sorting power of water in separating heterogeneous masses of material into their constituent parts, and placing each where it will do the most good.

The largest and one of the most interesting earthen dams ever built, has recently been completed at Gatun on the Isthmus of Panama. It impounds in Gatun Lake the waters of the Chagres River, and thereby forms the summit level of the Panama Canal, extending from Gatun, about seven miles from the northern terminus of the canal, through the Culebra Cut to Pedro Miguel, a distance along the sailing route of the canal of 32 miles. The area of Gatun Lake at normal high water is about 165 square miles, and its depth about 75 feet. It thus follows that this dam is one of the most important structures

on this great work. The Gatun Dam, as finally built, contains about 21,000,000 cubic yards of earth and rock, most of it being clay pumped into place by hydraulic dredges. The bottom of the valley is about 10 feet above mean sea level and a wide cut-off trench carries the base of the dam slightly below sea level. Its top is about 105 feet elevation, or 20 feet above normal high water in Gatun Lake. Its maximum width of base parallel to the valley is over two thousand feet, the upstream slopes averaging about 7 to 1, and the downstream slopes varying between 8 to 1 and 16 to 1, with an average of about 12 to 1. These conservative lines were adopted for a number of reasons, among which the following were the most important:

1. The extremely soft, yielding foundation made it imperative to avoid any large increase of load on any portion over that on the ground adjacent. Hence, steep slopes had to be avoided, especially on the downstream face.

2. The hydraulic fill being presumably less pervious than portions of the natural foundation, it was desired as a blanket to the latter, so as to enforce a long line of travel for percolating waters, and to fortify against boils and blow-outs below the dam.

3. The extreme importance of the structure to the integrity of the canal emphasized the importance of using very large factors of safety against destruction by both natural and artificial forces.

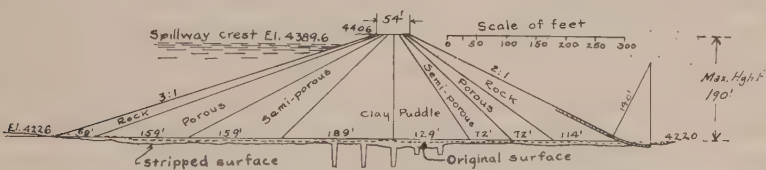
The Consulting Board of 1905, which outlined the lock canal project involving the Gatun Dam, gave greatest weight to the second consideration above named. That Board proposed to carry the dam to an elevation of 135 feet above sea level, thus giving a freeboard of 50 feet above normal high water.

Subsequent experience convinced the Consulting Board of 1909, that instability of foundation, and of the material of which the dam was to be built was the greatest difficulty to be overcome. Hence, the large freeboard proposed would prove a menace by unnecessarily overloading the foundation at the axis, and it recommended a reduction of height to 115 feet above sea level, thus reducing the freeboard from 50 feet to 30 feet. Further experience led to an additional reduction of

ten feet in height, which is doubtless an improvement in stability, besides saving cost.

Even with such flat slopes as 7 or 8 to 1, difficulty was encountered in holding the hydraulic fill in place till it could be drained and consolidated. In expediting this process, more than half the earth pumped into the dam was carried away with the drainage water. It is the opinion of those best able to judge, that with the conditions presented and materials available, it would not have been practicable to build the dam by that process on much steeper slopes than those adopted for the upper half of the dam.

The hydraulic method of depositing clay implies that it goes into place in a supersaturated condition, often containing 50% of water. The difficulty of holding supersaturated clay



DAM NO 2 AT NECAXA, MEXICO

Fig. 3.

in the interior of a high fill was vividly illustrated in the Necaxa Dam, which was constructed in Mexico for the Mexican Light and Power Co. Its construction by the hydraulic method was a bold undertaking, the supply canal alone costing $250,000, and the transportation, by running water, of large rock being a prominent feature of the plan.

The upstream slope was 3 to 1, and the downstream slope 2 to 1, both slopes being formed of fragmentary rock, while the interior mass was of clay, all deposited by water. The volume was 2,130,000 cubic yards, forming by far the highest earth dam ever built, its height being 190 feet.

Owing to the slow drainage of the clay body of the dam, it retained a semi-liquid consistency, and when the dam was nearly completed, the lateral pressure of the clay forced the water face into the reservoir, and about 750,000 cubic yards of material followed it. This impressive accident, as well as the

experience at Gatun, where bulging up of slopes was experienced, illustrates the instability of undrained clay, and the limitations of the hydraulic method of handling such materials.[7]

For handling sand, gravel, small rock, and mixtures of these materials with clay or silt, the hydraulic method has demonstrated its economy under favorable conditions, and it produces good results when its sorting powers are skillfully employed upon such materials, by depositing the finer particles in an impervious core, and the coarser, on the exterior slopes where they furnish efficient drainage on the lower side, serve as efficient protection against wave action on the upper side and lend stability against sloughing to both.

The Calaveras Dam in California, which will be the highest earth dam on record (250 feet) is now being built by the hydraulic method.

The hydraulic process requires great skill, and attempts are now being made to utilize it in the construction of banks in which the materials are to occur in well mixed condition, the clay to be retained in the interstices of the mixed sand and gravel. To this end, shear boards are used to guide the mixed water-born material in a way that will cause it to drop its load without segregation. To what extent this method can be made to produce the desired results remains to be seen.

In some cases, as in the Bumping Lake Dam in Washington (without core wall) and the Arrowhead Dam in California (with core wall), the hydraulic process has been used in washing material from the slopes into a central pool, the material having first been hauled and dumped on the slopes by mechanical methods. Such procedure has advantages where it is feared that the material as dumped cannot be rolled into a tight mass without expensive selection and waste, and where water under gravity pressure is available for cheap assorting and conveying to place.

Slope Protection.

The protection of the water slope of earthen dams is always an important and expensive problem, especially under the circumstances which often obtain in the West, where rock is not at hand, and the costly rail and wagon haul make cement expensive. Concrete has been extensively used for paving

[7] Transactions Am. Soc. C. E., Vol. 74, p. 38, Dec., 1911.

earthen dams in the eastern slope of Colorado, where wind action is severe. It is noted that with a smooth facing such as concrete affords, heavy winds cause the waves to roll up the slope far beyond the height of their crests, and thereby necessitate either greater freeboard or the construction of a parapet wall, such as was provided on the Minidoka Dam.

An interesting experiment is now in progress on the two large embankments that form the Deer Flat Reservoir of the U. S. Reclamation Service, which have a gravel facing. Wind action produced beaching and wearing down of materials. No rock was within reach for riprap. The embankments were widened at the top to a total of 60 to 70 feet by dumping gravel on the 3 to 1 water slope from cars, which was then allowed to lie at its natural angle of repose, to be worked down the bank by the waves. Wave action is expected to work the gravel down the slope gradually, the fine silt and sand settling in the bottom of the reservoir where it is much needed to check seepage under the dam, the coarsest material remaining on the slope. The degradation of the bank has been much slower than was expected, and the extra top width has nowhere been reduced as much as 25 per cent, and in some places hardly at all, in spite of the fact that the largest cobbles do not exceed 5″ in length and the reservoir has a very large wind exposure.

Indications along the natural gravel slopes of the Wachusetts Reservoir are that permanent slopes in such circumstances will assume an inclination of one to four or five, in which case further gravel may have to be deposited on the Deer Flat embankments in the future or other protection provided.

The concrete face of the Belle Fourche Dam was constructed of slabs 8″ thick and 5′ x 6½′ in size, laid on gravel backing which rests on the clay. The slabs were laid as closely together as possible in horizontal belts. It may be of interest to record here some damage which was done by a violent wind storm, which caused the waves to run high up the slope. Upon the waves receding, water would spout through the joints and the upward water pressure, of which this was evidence, caused a few slabs to be lifted up, breaching the slope protection. Little damage was done to the clay body of the dam, which was firm, and into which the water apparently had not pene-

trated. Repetition of such accidents has been prevented by drilling holes along the joints and filling them with mortar, thus keying the slabs together.

The introduction into the body of an earth dam of a drainage element brings us logically to the combination of earth and rock-fill dam, where a wall of dry rock filling is faced on the upper side with a relatively impervious bank of earth. Such dams are not numerous, being usually confined to conditions where the quantity of available and suitable earth is limited, and rock is available in its stead.

One of the early examples of hydraulic dam construction of this type is at Milner on the Snake River, Idaho, where a mass of sandy silt and gravel was sluiced against a loose rock backing, a wooden diaphragm being used to prevent loss into the rock. Other examples of the combination of earth and rock-fill are the Minidoka Dam across the Snake River, and two dams built by the Pecos Irrigation Company near Carlsbad, New Mexico, on the Pecos River. One of these, forming Lake McMillan, is still standing as originally built. The lower, at Lake Avalon, failed from overtopping in 1893, was rebuilt and in 1905 again failed. It is uncertain whether the second failure was caused by burrowing animals or some other cause, but it seems to be certain that it did not overtop. It was rebuilt by the U. S. Reclamation Service in 1907. In the reconstruction, a reinforced core wall was provided between the rock-fill and the earth facing to guard against burrowing animals, and on account of the poor quality of earth available at the site.

More recently, the United States has built a combination of earth and rock-fill, 33 feet high at Clear Lake, Oregon, in which a core wall was deemed unnecessary, and the passage of earth into the rock portion of the dam is prevented by having the upstream face of the rock-fill shade from coarse to fine.

In early days several dams were built in the West, of rock-fill, with a facing of lumber for water-tightness. These dams with their steep slopes show bold conception, were well adapted to local conditions, and have satisfactorily served their purpose. One of this type, near Walnut Grove, Arizona, was built in 1886 and 1887, and failed in February, 1890, because of a faulty foundation. A more recent example is the storage

dam near Escondido, California, 70 feet high. The water slope is $\frac{1}{2}$ to 1, redwood timbers were built into the rock wall, and to these was fastened a double layer of planking, backed with about two inches of concrete. A modification of this type is the storage dam of the Pike's Peak Power Company near Victor, Colorado, where a rock-fill is faced with a deck of steel plates.

Other examples are the 140-ft. dam on the Stanislaus River in California, with a reinforced concrete face, from 36″ to 9″ thick, resting against the rock-fill, the upstream part of which is hand and derrick laid, with a facing of 2 ft. laid in mortar; and the 150-ft. Moreno Dam, similarly constructed, the reinforced concrete facing having been left for future construction, the mortar filled portion being, however, 7 ft. thick.

CONCLUSION.

A number of serious accidents have happened to dams during the last twenty years, and in a few cases, large loss of life has been recorded. There has been little supervision on the part of public authorities over dam construction, but during the last few years such supervision is provided in many of the States, and this policy is spreading.

Considering, however, the searching effect of water and the impossibility of full knowledge of foundation conditions and of maximum run-off, the failures constitute an exceedingly small proportion of the numerous dam structures which have been built, and, on the whole, construction of this class furnishes a record of which the engineering profession has good reason to be proud.

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Mr. G. M. Houston,* M. Am. Soc. C. E., Mem. Can. Soc. C. E. (verbally), stated that of late earth embankments had been protected against wave action by concrete, plain or reinforced; where formerly rip-rap was used. In placing concrete for this purpose, the condition of the earthwork is of great importance. There are two methods of placing concrete for bank protection; either in small slabs with joints, as in the Belle Fourche Project, or in a continuous reinforced slab with expansion joints. In the speaker's opinion, unless the slopes are good, small slabs should be used, as they can be placed practically as rip-rap and repaired easily in case of settlement. When the slopes are good, the method of a continuous reinforced-concrete slab is best. The practice of increasing interior slopes from 3:1 or 5:1 to 1½:1 and covering with concrete, and of increasing outside slopes from 3 or 4:1 to 2:1, frequently has proved disastrous. Mr. Houston.

Mr. Gardner S. Williams,† M. Am. Soc. C. E. (verbally), stated that the multiple-arch dam has been used to a considerable extent in Michigan on soft foundations. That type of dam is adapted from the old lumbermen's dam of wood with flat platforms. An inclined multiple-arch dam was designed and contracted for before the issuing of the Jorgensen patents. Mr. Williams.

The first multiple-arch dam was built in India in 1806, being designed by an engineer of the British Army, whose name is unknown. That dam was semi-circular in plan, with vertical arches around the semi-circle. The head was not large, but the unit stresses developed were larger than had been allowed up to that time. The dam is still giving good service.

The second dam of that type was designed by Henry Goldmark, M. Am. Soc. C. E., for the Pioneer Power Company, Ogden, Utah, and is described in a paper by Mr. Goldmark in Transactions Am. Soc. C. E., Vol. XXXVIII, page 246. The third multiple-arch dam was constructed in Australia; and the fourth was designed and built near Ithaca, N. Y., by the speaker.

In Michigan multiple-arch dams have been constructed on clay and gravel foundations with properly spread footings for piers. The arches are of 45° inclination. Dams of this type are economical up to 40 feet in height, and probably up to 60 feet, but only on a rock foundation.

Speaking of movable dam-crests, attention was called to a bear-trap sluiceway for logs designed for the Great Northern Power Co. of Duluth, Minnesota. A 30-foot opening was required, and with the 20 feet variation in head, only three minutes is required for operation.

Replying to a question as to the best position for core-wall, the speaker stated that earth dams depend for their stability on the weight of the earth and that such stability is decreased by increasing the amount of the earth which is saturated. For that reason it might be

* Irrigation Office, Department of the Interior, Calgary, Alta., Canada.

† Cons. Engr., Ann Arbor, Mich.

Mr. Williams. preferable to place the impervious layer on the up-stream face, as is done in rock-fill dams. Another means to increase the stability of the earth dams is to reduce their saturation to a minimum by draining all of the earth below the center line of the dam. The line of saturation probably will pass from the water-surface on the back of the dam to the head of the drains. To put the cut-off at the center line of the dam does not increase the stability unless the saturation of the foundation is limited also.

Mr. Eastwood. **Mr. John S. Eastwood,*** M. Am. Soc. C. E. (verbally), stated that in the authors' paper prominence is given to the uplift or hydrostatic pressure exerted on the foundations of dams; but that some of the remedies proposed are based on doubtful assumptions. The amount of the uplift depends on the freedom the water has to "get away"; and is not much reduced by a retardation in the rate of inflow in or through the material of the foundation, as a reduction from such cause is contrary to the laws of hydrostatics. Time is not an element in such uplift, which will occur even if the rate of flow be very slow. The uplift is the result of a confinement of water under the dam and is best removed in the hollow types of dams which have a limited foundation area. To reduce uplift, stratified foundations should be drained the same as the floor of the dam; and for this purpose tunnels are the only satisfactory relief.

The speaker stated that the application of the correct basic principle of the design of masonry dams to any site suitable for a masonry dam, must include the arch, in some form, for a water-face or deck, with natural or artificial abutments or buttresses.

In the authors' paper, the Ambursen Company, which is the principal exponent of the flat-deck type of buttress dam, should have been given credit for the 84 dams of this type built by that company alone.

None of the single-arch dams mentioned by the authors on page 696 have constant radii from top to bottom, but, instead, have radii that increase from top to bottom, which is directly contrary to the economic principle of the constant-angle arch dam usually accredited to Lars R. Jorgensen, M. Am. Soc. C. E. However, H. H. Wadsworth, M. Am. Soc. C. E., designed and built the constant-angle arch dam for the California Debris Commission before the Jorgensen patent was applied for. The constant-angle design is extremely limited in its application.

Mr. Eastwood called attention to the advantages of the multiple dam with sloping deck, as exemplified in the Hume Lake Dam, the new Big Bear Valley Dam, the Los Verjales Dam, the Kennedy Dam, and the Malad Dam—all of which were built after his designs.

The speaker stated that the efficiency of the multiple-arch dam increases and its comparative cost decreases with its height; and that multiple-arch dams of 300 feet height are, in his opinion, entirely feasible.

* Cons. Hydr. Engr., San Francisco, Calif.

Mr. Griffin.

Mr. A. Griffin,* Assoc. M. Am. Soc. C. E. (verbally), mentioned two automatic siphon spillways in the controlling canals of the South San Joaquin Irrigation District, of which he is the chief engineer. Their throats are 2 ft. x 2 ft. with a head of 10 to 12 feet. They discharge 100 cubic feet per second each and are at slightly different angles. A priming siphon is used, which acts as a jet pump to force air out of the main siphon. Regulation of the water-level in the canal is accomplished to within 0.2 to 0.3 foot. An automatic siphon spillway is used also on the Brentwood Farms Project, but this spillway primes directly.

The speaker stated that, in his opinion, there should be two sets of gates for outlet pipes through earth dams, one set operating with great ease.

Mr. Trask.

Mr. F. E. Trask,† M. Am. Soc. C. E. (verbally), stated that he was consulting engineer of the Escondido rock-fill dam mentioned by the authors. That dam originally was designed for a height of 110 feet but was built only to 70 feet. The spillway was not built as designed originally; however, as there is no danger from floods, the dam is safe. On the new Little Bear Valley Dam, he consulted only on construction. That dam is of earth placed by semi-hydraulic process, with a concrete core-wall.

Mr. Wagoner.

Mr. Luther Wagoner,‡ M. Am. Soc. C. E. (by letter), stated that he investigated personally the reports of the failure of the Walnut Grove Dam and ascribes the failure to leakage under the dam through the foundations. He was told by a workman, whose duty it was to concrete the bed-rock at the toe of the wooden skin of the dam, that, due to inadequate pumping plant, part of such work was done in water 3 or 4 feet deep and the mistake was made by the engineers of considering boulders as bed-rock in this part of the foundation. A description of the failure of this dam is given in the Proceedings of the Technical Society of the Pacific Coast, 1888.

Mr. Quinton.

Mr. J. H. Quinton,§ M. Am. Soc. C. E. (by letter), stated that the progress for the last 30 years in the design and construction of various types of dams has been well set forth by the authors.

In the design of arch dams built of concrete, the effect of frost should be borne in mind upon thin arches of concrete under high heads of water. If water percolates through a concrete dam, the spalling or flaking of the surface concrete in frosty weather becomes a serious menace to the stability of the dam, tending to decrease its thickness each year and thus reduce its factor of safety against crushing.

The Shoshone Dam, built by the United States Reclamation Service, is a single-radius arch dam with its crest 240 feet above the bed of the stream; it is built of concrete containing about 25% of "pudding stones". It is located in a deep box canyon with granite walls, and at

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‡ Cons. Engr., San Francisco, Calif.

§ Cons. Engr., Los Angeles, Calif.

Mr. Quinton. a comparatively high altitude, where low temperatures prevail for long periods each year. The design of this dam has been criticized as being uneconomical, since the thickness at the bed of the stream could have been very much reduced by using variable radii in the design instead of a uniform radius from bottom to crest of the dam. One reason why the variable radii were not used in the original design of that dam is that concrete is a porous material, and water under such a high head as this dam now supports naturally will permeate a long distance into the concrete at or near the base of the dam. If the water should pass freely to the lower side of the dam, serious results might follow from the flaking of the surface concrete in freezing weather. Such permeation of the water already has been observed in a dam recently built on the multiple-arch system, although the water pressure was that due to only about 60 feet of head.

While the impermeability of concrete still is involved in much uncertainty, it may be assumed as axiomatic that water will find more difficulty in passing through a thick wall than through a thin one of the same material; and there must be a limit to the thinness of a concrete wall where it is expected to retain water under high heads in a region where low winter temperatures prevail. The loss of 3 inches of concrete by flaking from a dam 107 feet thick might not be alarming, but the same loss in an arch only 10 feet thick might be a serious matter.

As a precaution against percolation, the upstream face of the Elephant Butte Dam has been coated by the cement gun with a rich cement mortar (1 cement: 1 sand); but the reservoir has not been filled to its maximum capacity as yet, so that it is impossible at present to say if this mortar coating will be effective in preventing percolation. Also, even if there should be no seepage through this dam when the reservoir is full, still it will be doubtful whether this impermeability is due to the coating of mortar on the upstream face of the dam or to the impermeability of the masonry itself. It is hoped that valuable experience in this matter may be gathered in the next few years from observations on the behavior of various types of dams.

Mr. Jorgensen. **Mr. Lars R. Jorgensen,*** Mem. Am. Soc. C. E. (by letter), stated that the authors deal with essentials of dam construction so fully that there is little to add; however, he submitted discussion on certain points, as follows:

For very high and long dams, the straight gravity-mass masonry dam yet seems to be the best type; although the material in a gravity dam is uneconomically distributed. With the reservoir full, the material in this type of dam is worked to only half of its efficiency. The addition of material to the section or profile is an uneconomical means to provide against uplift pressure, because the material thus added increases the area of the base exposed to uplift. In dams of medium height, the material added to compensate for uplift should not be distributed evenly along the bottom of the dam but should be added in the shape of but-

* Elec. and Hydr. Engr., San Francisco, Calif.

Mr. Jorgensen.

tresses on the downstream side, spaced 50 feet or more apart. This disposition of the masonry would increase greatly the stability and factor of safety of the dam. In high masonry dams, the unit foundation pressure at the toe of such buttresses would be greater than it is now customary to permit. Some more economical means of taking care of the uplift pressure than the mere widening of the section is very desirable; but at present that seems to be the only method that can be employed on high masonry dams.

For long dams of low or medium height, structural dams are more economical and safer than those of the gravity type. Of the different kinds of structural dams, Mr. Jorgensen is most familiar with the multiple-arch type. Those dams are very safe and economical up to say 120 feet high; but they are most economical for heights up to 50 or 60 feet, at which heights the buttresses and the arches contain about the same amount of material. At 120 feet the material in the buttresses is about two and one-half times that in the arches, the stiffening struts between buttresses being included with them. For higher dams the buttresses require a still larger proportion of the total material; and, besides, the structure probably would begin to appear flimsy at greater heights. For medium heights the multiple-arch dam is as economical and safe a structure as ever has been devised. It has a natural tendency to be water-tight under load; and while the unit cost of the material in place is higher than that of the gravity type, it requires enough less material to build it to reduce the total cost to say one half that of the gravity type.

Whenever the canyon is "narrow", a single arch is the most economical. The term "narrow" in this connection is a function of height, and for very high dams the top width may be considerable and the single arch still be economical. Whenever the canyon is narrower at the bottom than at the crest of the dam (which usually is the case) it pays to so shape the arch that it encloses as nearly as practicable a constant angle at all elevations. This angle should be chosen around 120° at the crest of the dam, if the contour of the rock abutments will permit of such a large angle. Toward the base of the dam it seldom will be practicable to keep up this large angle; but the larger the central angle is chosen at the crest, the larger will be the average value, which is the condition which should be aimed at. The mere changing of the length of the upstream radius is only of secondary importance (that cannot be helped), but it is the keeping up of the high average value of the central angle subtended by the arch that effects economy.

The principal reason that the old Bear Valley Dam must be regarded as an economical structure, is because of the very high arch stresses used in it. The continued stability of this dam during 40 years has done more to convert many skeptical engineers to belief in the soundness of the arch theory than has anything else. The Bear Valley arch is very flat, subtending only about 53° at the crest and less than half of that 48 feet lower down at the off-set, where the radius changes and where the por-

Mr. Jorgensen.

tion of the dam stops in which real arch action takes place. Had this arch been designed in accordance with the constant-angle arch principle and the same amount of material used in the arch, the arch stresses could have been brought down to very conservative amounts. On account of the high cost of cement there, a multiple-arch dam on this site would have been the cheapest of any first-class structure; and when it was desired to increase the storage recently and it was realized that it would be unsafe to add to the height of the old dam, an Eastwood multiple-arch dam was constructed just below the old dam.

The greatest difficulty in the construction of dams is to make the structure water-tight. In arch dams having a fairly thin section this generally is not so difficult as it is in arch dams with very thin sections. For arch dams of slender section, a rich concrete is used, or should be used; a slender arch often can compensate for temperature drops and shrinkage by deflection without cracking; and in slender sections the arch action is most complete. All three of these factors tend to prevent leakage. In a heavy or thick section, the upstream portion of the arch may be made of a rich concrete and the face plastered with a cement gun (the upstream face of thin sections also should be plastered in this way). The heavy section should be provided with contraction joints, and these are liable to cause some leakage. The arch action in a heavy section is not so pronounced along the upstream face, and hence the axial compression does not help to tighten the dam so fully as in thinner sections.

To lessen the liability of the contraction joints to leak and to increase the arch action in a heavy section and make it dominate over the cantilever and beam action, Mr. Jorgensen suggests the following procedure, which he hopes to try at the first opportunity:

When the dam is built, a system of pipes for grouting purposes should be inserted in the ends of the dam, straddling the contraction joint near the upstream face, but on the downstream side of the water-tight cut-off in the contraction joints. These pipes should be provided with slots in line with the contraction joints, the slots being protected from filling up with concrete by a covering of cheese-cloth and paper.

When the reservoir is empty in cold weather and after the dam has been in use say two seasons (and the masonry therefore has dissipated its chemical heat and taken its permanent set) grouting should be done through movable pipes inserted in the stationary pipes already built in the body of the dam. The movable pipes necessarily are smaller in diameter than the stationary ones, and the space between the stationary and the movable pipes should be closed by a packing at the lower end of the movable pipes. The grouting should proceed from the bottom up. By that time (2 seasons) the contraction joints probably will have opened up at least ⅛ in. and the paper and cheese-cloth wrapping perhaps will have cracked before the grout pressure reaches it. When the lower slots refuse to pass more grout under a pressure of 50

to 100 pounds per square inch, the movable pipe is to be pulled up say 30 feet to the next set of slots, etc. Mr. Jorgensen.

In this way it is believed that the whole contraction joint can be closed successfully under compression. When the reservoir begins to fill and the load begins to be applied, an axial compression exists already with its maximum value along the upstream face, thus tending to improve water-tightness and giving the drainage system less to do. Later, when the reservoir is full, the arch stresses will be distributed more uniformly over the whole section, than without this greater initial axial pressure on the upstream portion. It should be kept in mind that the greater the leakage, the greater is the danger of leaching valuable ingredients out of the concrete; and, also, that if initial arch compression can be put on the arch, it will take up a greater proportion of the total load than otherwise, and therefore be a safer structure.

Mr. H. Hawgood,* M. Am. Soc. C. E., Mem. Inst. C. E. (by letter), stated that the subject of Messrs. Davis and Henny's paper is of more than ordinary interest. Expansion of the productive areas of the world depends largely upon the conservation of water; and any advance in the design and construction of dams, whereby their cost may be lessened without sacrificing their safety, will extend the field of practicable conservation. Mr. Hawgood.

In the water-supply of a large city, cost may not be the controlling feature; but in the reclamation of arid or semi-arid lands, where the creation of the water-supply must precede the coming of the farmer and the earnings must justify the outlay, cost is the dominating factor.

The introduction of the hydraulic method of constructing earth dams has reduced their cost greatly, and thus rendered financially practicable the construction of many dams, the cost of which by the dry method would have been prohibitory.

In masonry structures, the high cost of the ponderous gravity dam has led to the use (when conditions permit) of lighter structures of the arch and other types, not depending upon their weight for stability. He would confine his remarks to dams dependent upon arch action for their stability.

In his paper upon the Huacal Dam, Mexico,† will be found particulars of 20 or 30 dams in various parts of the world in which the arch principle has been employed successfully. The oldest of these structures is the Meer Allum Dam, Hyderabad, India, which has been in service for over a hundred years. It is an interesting example of what may be done with multiple arches. The length of the dam is about one-half mile, and it is made up of a series of nearly semicircular brick arches, with radii of 70 to 147 feet and a height of about 40 feet.‡

Among single-arch dams, the Barossa Dam in South Australia (built 11 years ago) has a crest length of 472 feet and a water depth of 94

* Cons. Engr., Los Angeles, Calif.

† Trans. Am. Soc. C. E., LXXVIII, page 564.

‡ Min. of Proc. Inst. C. E. Vol. 172, p. 214.

Mr. Hawgood. feet; and the Parkes Dam in New South Wales (built 18 years ago) has a crest length of 540 feet and a water depth of 37 feet.** These lengths of existing structures dispose of a somewhat prevalent impression that arch-action dams are applicable only to narrow gorges.

Dams are so situated, in most cases, that their failure would entail destruction to life and property in the valleys below; hence, the question of safety always is or should be superior to that of cost.

In respect to safety, the arch dam appears to occupy a very sound position. Search and inquiry on Mr. Hawgood's part so far has failed to discover a single instance of the failure of an arch dam, notwithstanding that at least two such dams (the old Bear Valley and the Otay Dams, both in California) have extremely thin sections. In both these dams the masonry is subjected to compressive stresses of more than 60 tons per square foot, or to stresses more than twice those considered conservative.

Two serious elements of danger to the gravity dam are absent from the arch dam—uplift by infiltering water and sliding on the foundation rock; the latter, however, can exist in a modified degree in multiple-arch dams.

The precise mathematical determination of the stresses in an arch dam is impossible. Too many unknown quantities and conditions enter into the problem, and, consequently, too many assumptions have to be made, to make it possible to arrive at exact results. In this respect, however, the arch dam is not inferior to the gravity type. As said several years ago by as eminent an authority as Dr. W. C. Unwin, "it is hopeless to attack the dam problem by pure mathematics". The futility of attempting a purely mathematical determination of the stresses in dams now is generally recognized; and it is admitted that coefficients derived from practice must be introduced, as in every other field of engineering.

One assumption commonly made in connection with arch dams, Mr. Hawgood considers entirely erroneous; that is the assumption that the foundations are absolutely fixed and rigid. If it be assumed (as usually) that the masonry of the dam itself has elastic properties, then logically, elastic properties must be ascribed to the foundation rock itself—especially if (as is usually the case) portions of the self-same rock are incorporated in the concrete or rubble masonry of the dam. If it be granted that the bed-rock is capable of compression and elastic deformation, then the vertical weight of the water on the rock floor above the dam (greatest at the dam) must produce elastic deformation in the rock normal to the vertical load, and such deformation (taking the line of least resistance) must be greatest in the downstream direction. However small this movement may be, it cannot take place without deflecting the crest of the dam and in some degree calling into play arch action. This view of the situation is supported by the fact that

** Min. of Proc. Inst. C. E., Vol. 178.

comparatively thin arch dams are not broken away from their bases, as would occur inevitably if they were subjected to the severe bending stresses which would be caused by an absolutely fixed and rigid base. Mr. Hawgood.

The mathematical analysis of arch dams should not be neglected nor its value under-estimated; at the same time it should be borne in mind that many assumptions are involved in such analysis and that the results obtained cannot be more accurate than the assumptions themselves.

The arch dam can be used with marked economy in many situations; it has passed the experimental stage and should receive greater attention than it has been accorded heretofore.

Messrs. Davis and Henny.

Messrs. A. P. Davis and **D. C. Henny** call attention to the discussion of Mr. Gardner S. Williams where he refers to the desirability of increasing the weight of an earth dam by draining its downstream portion. In dams of ordinary dimensions there is not the slightest danger from sliding, even assuming the entire mass of the dam to be fully saturated, since with 3 to 1 and 2 to 1 slopes the submerged weight will be from four to seven times the horizontal water pressure, according to the height of the dam and the assumed percentage of voids in the dam material.

Sliding may take place after a section of the dam has been weakened by sloughing, and drainage is essential if the downstream portion of the dam is otherwise liable to slough.

If the downstream portion of a dam consists of material which with the existing bank slope is in no danger of sloughing, even when fully saturated, and if the saturated foundation material is sufficiently firm, drainage is unnecessary and may become harmful by steepening the water gradient through the dam. This will tend to increase the seepage and may establish distinct lines of water flow towards the drain heads. The harm that may result thereby is increased if the dam rests on a pervious foundation through which piping may take place. In the case of one of the two embankments of the Deer Flat Reservoir in Idaho, which rests on a pervious foundation and consists largely of sand and gravel, a strip of ground downstream from the dam has been blanketed with sand and gravel to a depth of from 4 to 6 ft. for a width of about 100 ft. Such blanket has in one sense the opposite effect of drainage, in that it permits a counter water pressure to be built up, thereby flattening the water gradient through the dam and tending to diminish seepage both through the dam and its foundation.

The discussion has brought out the interesting fact that new designs of masonry dams have been the result of slow evolution. Sloping flat concrete deck supported by buttresses, as in the Ambursen type dam, was preceded by similar construction in wood. The vertical multiple arch appears to have been used in India, according to Mr. H. Hawgood, over a century ago and the sloping multiple arch, used recently with great success by Mr. John S. Eastwood, was fully described by Mr. Henry Goldmark in 1897, as mentioned by Mr. Williams. Similarly, according to Mr. Eastwood, the constant-angle arch-dam design, the economy of

Messrs. Davis and Henny.

which was recently demonstrated by Mr. Lars R. Jorgensen, appears to have been previously used by Mr. H. H. Wadsworth in the construction of a dam for the California Debris Commission. All of the engineers mentioned deserve full credit for excellent work in advancing dam design and construction. In this connection Mr. Luther Wagoner might well be mentioned as the designer of the La Grange Dam, believed to be the highest overflow dam in existence.

Mr. J. H. Quinton calls attention to the danger of frost reducing the thickness of concrete and thus limiting the life of a dam with thin curtain walls. The La Prele Dam in Wyoming, the highest flat-deck reinforced dam built by the Ambursen Co., shows serious flaking, but whether this is due to frost or other causes has not been definitely determined.

Mr. Jorgensen's statement that in the case of a solid masonry dam the widening of the section is the only method that can be employed for taking care of uplift is surprising in view of the grouting and drainage methods employed in the case of many high masonry dams recently built, including the Elephant Butte and the Arrowrock Dams, as fully described in the paper.

Paper No. 48

EARTHEN DAMS.

By

WILLIAM LUMISDEN STRANGE, M. Inst. C. E.
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INTRODUCTION.

In this paper the Author proposes to deal first with the general principles which govern the construction of earthen dams and then to describe how effect is given to them in executing such works in India, with certain modifications which have suggested themselves to him. Forms of construction favoured in America will be briefly noticed; and short descriptions of matters in connection with waste weirs and outlets, the principal subworks of earthen dams, will be given.

GENERAL PRINCIPLES.

Theory and Practice.

Properly designed and constructed earthen dams are amply sufficient to withstand the pressure of the water which they hold up. The only way water can and does act prejudicially against them is by infiltration, which diminishes their frictional resistance and adhesion. There have been many mathematical investigations as to the behaviour of earthwork but these have been based on laboratory experiments, in which it was treated as a homogeneous material, and the investigators did not take into account all the variations in the soils and in construction which occur in practice. These experiments are, however, most useful in indicating the nature of the forces at work, although they cannot demonstrate their actual intensi-

ties. With respect to earthen dams, engineers, therefore, prefer to be guided by experience rather than pure theory, and they are supported in this view by leading investigators.

Friction and Adhesion.

Earthwork gives way by the sliding, or slipping, of its parts, as they are not in rigid connection with each other. The resistance to this motion is due, partly, to the friction between the particles, and, partly, to their mutual adhesion or cohesion.

The friction is measured by the angle of repose, and constants for it for different soils have been determined: these are coefficients of the weight of the mass. Friction is greatest for coarse and least for fine soils; on it depends the permanent stability of natural earthwork. A slight addition of moisture increases the coefficient of friction, but an excess of water acts as an unguent in diminishing the friction.

The adhesion, or cohesion, may be measured by the depth to which an unsupported face of earthwork will stand, before that face is affected by the weather: it gives additional stability to earthwork. It is an extremely varying force; it is increased by a moderate amount of moisture, but is diminished by excessive wetness.

It is, therefore, evident that any given earthwork, other things being equal, will be most stable when slightly damp and least stable when charged with water. Moreover, wet soils have their particles separated by the contained water and cannot be fully compacted—thus they are diminished in weight and increased in porosity. Hence the stability of earthwork depends upon the facility and thoroughness with which it can be drained of superfluous and dangerous water.

The ''Historical Element''.

There is a further cause of variation in the behaviour of soils, and that is what Professor Clerk Maxwell has called the ''historical element'', which term not only comprises the manner in which the mass was formed, but also includes the different causes at work which have subsequently modified its condition. Experiments with sand, made in different ways into an embankment, showed that it produced different amounts of thrust, although in each case the mass presented the same ex-

ternal appearance. Practical experience is in accordance with these investigations, for, when it is desired that earthwork should settle tightly against a retaining wall, its constituent layers are made to slope downwards to the wall; the steeper the slope, the greater will be their pressure. If, however, the wall is to be freed from earth pressure, the layers are made to slope downwards from it.

This matter has not, however, always received the attention it deserves, as in nearly all earthworks the practice is to treat the material as homogeneous from top to base and to adopt uniform slopes throughout. The lower portions in a high dam must, however, be in a very different condition from that of the upper ones, as they are much more highly compressed and are moister. Probably the enormous superincumbent weight causes some stratification of the lower parts and diminishes their cohesion, while the increased smoothness due to the pressure lessens their frictional resistance. The amount of increase of frictional stress, according to the depth below the surface, depends upon the viscosity of the earth enabling it to transmit pressure, and this pressure must vary from point to point on the cross section of the dam. The increase in moisture at the base will diminish both the frictional resistance and the cohesion. The variation of the materials and the differences in their disposition and the methods of construction introduce further elements of change, so that there are numerous entirely hidden forces at work, of which the magnitude and resultant action can be determined only from the experience of the works themselves.

It may, however, be said that in a high earthen dam with plane slopes the resistance to slipping decreases with the increase of height from the top, and that the proper section for it is one having the slopes continuously flattened towards the base. Experience has shown that well constructed dams up to 75 feet in height can be formed with the same slopes throughout: ones of greater height it will be advisable to construct with varying slopes, with berms at the base, or with strong toes of drystone (packed with good gritty and clayey soil to make them fairly watertight and to increase their resistance to slipping).

PERCOLATION AND DRAINAGE.

Percolation.

Although proper puddle clay is highly resistant to infiltration by water, all ordinary earths used for dam construction are much less impervious. Infiltration from the reservoir will decrease the weight of the submerged part of the work by the weight of the water displaced by it, and will thus diminish the stability of the dam in proportion to its porosity. Conversely, the heavier the material of which the embankment is constructed, other things being equal, the more stable will be the structure. The effect of the degree of porosity on resistance to infiltration is illustrated in Fig. 1, where are shown the surface lines of percolation in different cases.

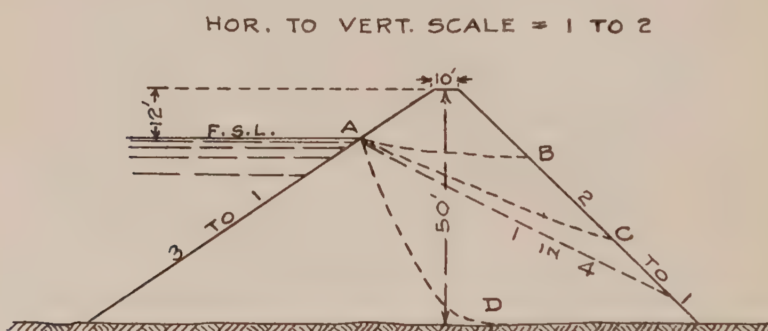

Fig. 1.

The line AB, nearly level, represents what would occur in a bank of dry rubble with large interstices; the stones being comparatively large, the bank would be stable until the velocity of the water between them increased sufficiently to carry them away. The line AC indicates what might happen in a badly constructed dam, and the amount of infiltration shown would probably cause a slip. The line AD marks what exists in a properly constructed embankment, more especially if its downstream portion is formed of self-draining material and is underlain by base drains. The line marked "1 in 4" is that which experiments in Bombay dams have shown to be, there, an average slope for the percolation surface: these experiments

were made by sinking iron pipes, from 1½ to 2 inches (3.8 to 5.1 cm.) in diameter, with perforated ends through the embankments, and it is possible that the infiltration water was headed up in them by the internal pressure on it; moreover, the dams were made when the importance of drainage was not realized.

The slope of the percolation line measures the resistance of the material to the flow of water through it, and the decrease in weight and stability of the dam is measured by the height at any point of the percolation line above the ground line. In addition, the saturated portion has diminished frictional and cohesive resistance to slipping. It is, therefore, of the greatest importance to construct the upstream part of the section of the dam with impervious material and to increase its resistance to infiltration by thorough consolidation.

If percolation to a small extent took place uniformly through a solidly founded dam and did not carry away any of its material, it would not sensibly affect its stability—as is proved by many existing dams, of which few are impervious, and in cuttings through leaking strata. The danger is that the percolating water may sodden the base or may be concentrated from a length of the dam and will endeavor to find an outlet, such as a settlement crack or pervious layer. If successful in this, the flow may be able to detach from the main part of the embankment the portion of the earthwork thus separated and cause it to slip. As long as the percolation water issues clear and does not increase in amount, there is no fear that an accident will happen from it directly. Percolation can be reduced by careful selection and proper consolidation of the material used in the construction of the dam; such percolation as still takes place should be dealt with by drainage.

Drainage.

Drainage is necessary to remove water which may be met with—in the heart of the dam, due to percolation from the reservoir or the wetting of the downstream slope by rain; or, along the junction of the base of the dam with the ground; or, through the strata underlying that base. The two latter are due to leakage from the reservoir.

To prevent the internal percolation from entering into and

remaining in excess in the embankment, its upstream portion should be constructed of clayey material and its downstream portion of material with more grit in it, to render it self-draining, and both should be well consolidated.

To deal with the leakage along the base of the dam, the surface of the natural soil should be excavated in a series of longitudinal furrows, or "foundation benches", parallel to the centre line, with the long slope next the toe, and small "foundation trenches" should be dug at their troughs. On the upstream side of the dam these latter should be filled with watertight material, so as to make them into small puddle trenches which will tend to resist the creep of water, to form an impermeable base for the dam and to aid the main central puddle trench. On the downstream side of the dam the trenches should be filled with gravelly, porous material, so as to convert them into small "foundation drains" which will receive the water creeping along the surface of the foundation and that derived from the percolation through the dam, which will be led uniformly into them by the slopes of the benches. This drainage will be passed out of the dam at intervals by cross drains. To stop water from lodging downstream of the downstream toe of the embankment and soddening the ground, which might induce a slip, it is advisable to excavate a longitudinal "surface drain" parallel to and next that toe.

To cut off leakage through the strata underlying the dam, a puddle trench is made, and this is usually the only precaution taken. Some leakage is, however, likely not to be intercepted by it, and this will tend to soften the puddle and sodden the impermeable strata immediately downstream of the trench. To deal with this flow, it is desirable to construct a longitudinal "puddle trench drain", with a continuous fall along the downstream toe of the trench, and to lead the water out of the dam by cross drains. If there are depressions in the longitudinal section of the main drain, its bed should there be supported at the proper inclination by masonry or concrete filling. Where the trench crosses the bed of the impounded stream at a low level, its drain can be drained into that bed by an upwardly-inclined cross drain, up which the internal pressure will cause the water to flow. Still further to prevent the ground down-

stream of the dam from becoming sodden and incapable of resisting the weight of that heavy mass of earthwork, a "downstream drain" should be formed downstream of the surface drain and into it should be led the discharge of the foundation, surface and puddle trench drains, and this should be passed out of it by cross drains, where practicable, or into the river bed. These drainage arrangements are shown in Fig. 2.

All these drains should be in discontinuous lengths terminating at the cross drains and separated from each other, there, by short lengths of undisturbed soil, so as to obviate long, continuous lines of drainage under or near the dam. All subsoil drains should be constructed on the principle of the "reversed filter", i. e., surrounded by fine porous material to prevent them from choking. The effect of this will probably be that in course of time the drainage will become staunched at its source by the deposit of silt. What has to be aimed at is to diminish, as far as possible, the flow of water in or under the dam upstream of its centre line, and, downstream of that, to lead harmlessly away such as has not been intercepted.

At all valley lines crossed by the embankment there should be "rear drains", and down the bed of the impounded stream a "main rear drain"; all these should be run at right angles to the dam, with as steep a slope as possible out to the natural surface. As long as the drains run clear and their discharge does not increase in the fair weather, it shows that damage is not happening to the embankment. Should, however, the flow become discoloured, it is a sign that a leak is forming, and this should be dealt with at once by cutting out the unsound part of the dam and remaking it. A proof of the efficiency of the drainage arrangements will be afforded by the dry condition of the ground downstream. If, however, swampy places exist there, they will show that the drains are not working properly and the defective lengths should be put right. With good drainage a well-designed and well-constructed earthen dam is rendered quite safe; as thereby the line of saturation is lowered and the foundations are secured, and thus slips are prevented. Undrained clay dams are liable to failure owing to the effects of percolation into them.

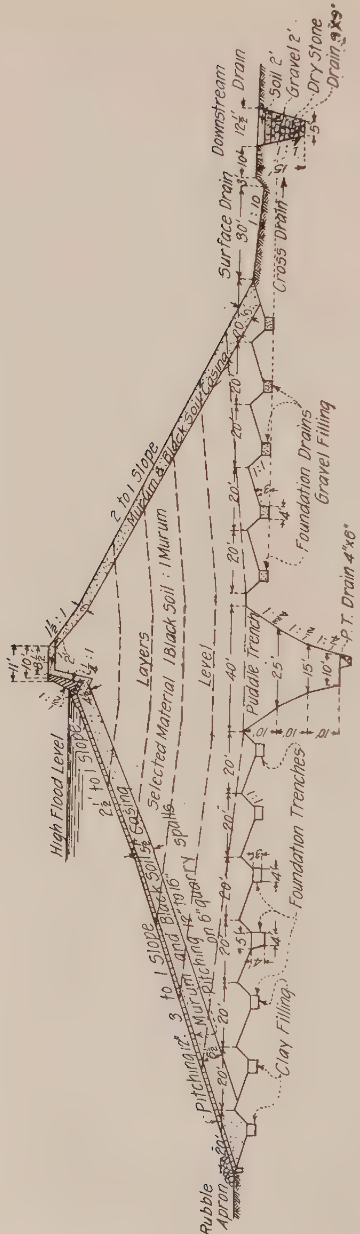
Downstream Drain
Soil 2'
Gravel 2'
Dry Stone Drain
Surface Drain
Cross Drain
2 to 1 Slope
Murum & Black Soil Casing
Foundation Drains
Gravel Filling
P.T. Drain 4"x6"
Layers
Selected Material 1 Black Soil : 1 Murum
Level
Puddle Trench
High Flood Level
Foundation Trenches
Clay Filling
Rubble Apron
3 to 1 Slope
Murum and Black Soil Casing
Pitching

Fig. 2.

AMERICAN DAMS.

The "Hydraulic-fill" Dam.

The "hydraulic-fill" dam is much favored in America. To form it, water is pumped, or delivered from reservoirs, at high pressure through pipes which end in a nozzle, so as to force the water to issue as a jet; and this jet is directed against an elevated earth and gravel face for the purpose of cutting it down. The resulting mixture of water and soil dèbris is then led by gravitation through pipes or wooden flumes on to the site of the dam, where it is deposited after "water-sorting" has taken place, so that the section is built up with the rocky particles on the outside faces and the other materials graduated to be finer and more clayey the nearer they approach the centre.

In the original practice a "summit pool" was formed on top of the dam as it was raised so as to hasten the deposit of the material and its consolidation by water pressure, and, thereafter, the water was drained off, partly through the dam itself. The result of this was, however, to induce stratification (tending subsequently to leakage) and to keep the central part of the dam as a soft, slimy clay charged with water (instead of being dense and watertight like a puddle wall), and this led to slips. The sides of the summit pool were formed by rough banks, which rendered difficult the proper formation of the final slope. The outside of the slope was deficient in clay and fine material, so that it was highly permeable and thus admitted to the hearting, while in a green state, water on the upstream side which was derived from the sluicing operation and impounded by the dam. This prevented the drainage of the hearting and its consolidation (as thereby intended to be effected), so that slips sometimes resulted.

In more modern practice, the defects mentioned above have been avoided. The water is not allowed to stand as a summit pool on the embankment but is run off at once. The material is deposited as a homogeneous mass, without stratification, by continually changing the dumping point; is compelled to flow longitudinally, with a perfectly free discharge; and is confined laterally by rough wooden shutters supported by posts set out to the correct side width and raised from time to time to keep pace with the embankment.

For successful construction by this system it seems essential that—

(a) A hearting of pure retentive clay and permeable side facings should not be formed, but the whole section should be of watertight and self-draining material;

(b) The work should be carried up slowly and evenly to the full section, and great care should be taken to avoid stratification;

(c) As much time as possible should be allowed for the work to drain and consolidate before it is subjected to infiltration from the reservoir.

Masonry Core Walls.

A masonry core wall is preferred by American engineers to a central puddle wall. The wall should be founded on an unyielding, impervious stratum; should be thick enough to resist infiltration and pressure due to the full head of water, and rupture by unequal earth pressure; and should have its faces gently battered, so that the earthwork of the dam during and after settlement may abut tightly against them. The following advantages are claimed for the core wall:

(a) It prevents the water percolating through the upstream slope of the dam from passing into the downstream one. (Thin masonry is, however, not absolutely watertight under water pressure, but may be made more staunch by cement pointing or plastering the upstream face.)

(b) It cannot be washed out, as a puddle wall may be, should a leak through it be formed: such a leak is more likely to be silted up than enlarged.

(c) It separates the dam into two distinct portions, an upstream one which should be made as watertight as possible, and a downstream one which should be formed as stable as possible. If the two portions abutted directly on each other, cracks might occur in the centre of the dam on account of differences in their settlement. (Such different settlements might, however, still happen if the core wall were built, and might lead to its fracture.)

(d) It enables the outlet culvert to be carried through the dam with perfect safety.

(e) It allows the outlet tower to be replaced by a "dry well" tower (built upstream of and in connection with the core wall), and an inlet channel from the reservoir and an outlet channel downstream—thus dispensing with the ordinary external tower and approach bridge and bank.

(f) It gives an earthen dam greater strength to resist the erosive action of water passing over its top. (This topping of a dam should be prevented by providing sufficient waste weir discharging power, and water should never be allowed to rise within several feet of the top of the dam.)

(g) It can be made to form a solid support to a crest wall protecting the top of the dam from wave action. For this purpose, the line of the core wall should be moved upstream to coincide with that of the upstream edge of the top of the dam. (Care will have to be taken to prevent the reservoir water getting direct access between the wall and the earthwork.)

INDIAN DAMS.

Conditions in India.

The following are the conditions which have to be met by engineers in India. The rainfall is almost entirely confined to the monsoon months, and is very capricious in amount and intensity. The rest of the year is generally characterised by a total absence of rain, and during this period a fall seldom occurs sufficient to produce replenishment. Owing to these climatic conditions, and also to the tropical heat and storms, a large amount of storage has to be effected, and a large provision for the safe discharge of floods has to be made.

Constructional work is practically impossible during the rains, and the programme for the execution of the work has therefore to be confined to the seven fair-weather months of the year. The labour available, although ample, is unskilled, and the amount of skilled supervision is limited. Proper puddle clay is rarely found but other materials for construction

are abundant. Owing to the cheapness of labour, mechanical appliances are little used, but carts, trams, rollers and simple pumps are employed on the construction of dams.

General Design.

An ordinary earthen embankment may be formed in one of the following ways, with:

(a) A puddle wall at the centre, or, on the water slope, or, in some intermediate position

(b) A clay hearting supported on each side by more stable material (this hearting is practically a very thick puddle wall of material inferior in water-tightness to puddle)

(c) A homogeneous section without a puddle wall

In English practice, (a) with the central puddle wall is the type generally adopted; in recent practice in India, (b) has been followed; while the earlier dams there were constructed of black "cotton soil" throughout according to (c), which, with the important modification of these examples that will be described later, is the type now recommended.

The Section of the Dam.

The proper section to be adopted for a dam depends upon:

(a) The angles of repose of the soil of which it is formed when saturated by the water of the reservoir or by rainfall

(b) The nature of its material

(c) The nature of the foundation

(d) The height to which the work has to be raised

(e) The importance of the work

The following table gives the general sections which may be adopted with safety and economy for all ordinary good soils properly consolidated and resting on good foundations:

Height of dam above ground level	Height of top of dam above high-flood level Feet	Top width Feet	Ratio of horizontal width to vertical height		Width of dam at high-flood level Feet
			Up-stream slope	Down-stream slope	
15 ft. (4.57 m.) and under........	4-5 (1.22 to 1.52 m.)	6 (1.83 m.)	2 to 1	1½ to 1	20-23½ (6.10 to 7.16 m.)
15 ft. to 25 ft. (4.57 to 7.62 m.)	5-6 (1.52 to 1.83 m.)	6 (1.83 m.)	2½ to 1	1¾ to 1	27¼-31½ (8.30 to 9.60 m.)
25 ft. to 50 ft. (7.62 to 15.2 m.)	6 (1.83 m.)	8 (2.44 m.)	3 to 1	2 to 1	38 (11.58 m.)
50 ft. to 75 ft. (15.2 to 22.86 m.)	7 (2.13 m.)	10 (3.05 m.)	3 to 1	2 to 1	45 (13.10 m.)

Above 75 feet (22.86 m.) in height special precautions have to be taken. These may consist in flattening the slopes considerably at the base, adding berms at the base, or constructing strong drystone toes. There are several instances of dams in England and America having been raised to 100 feet (30.5 m.) and a few to 120 feet (36.50 m.).

It is advisable for appearance sake to have the same section throughout the dam, as reductions at the flanks do not effect much saving, unless these are very long and moderately high. In a long dam, three changes at most will suffice, different sections being adopted for the gorge embankment and the high and low parts of the flank embankments. To facilitate the work of setting out, such changes should be made in lengths of 100 feet (30.5 m.) or 200 feet (61.0 m.), instead of uniformly throughout the whole dam.

Settlement.

When considering the section, the effect of settlement on the dam should be taken into account. In India, as a liberal allowance for the sake of safety, from 1/30th to 1/36th is added to the height for ordinary settlement, and is provided for in construction. Undue and excessive settlement may pos-

sibly take place, and particularly at the highest and most dangerous part of the embankment. To provide for this, the top width should not be diminished nor the side slopes steepened so much as to prevent the further raising of the work, should such settlement occur, and the "free-board" of the dam, or its height above high-flood level, should be ample. Naturally, more liberal allowances should be made at the high parts than at the low ones of the embankment.

The Gorge Embankment.

Particular care is required at the gorge or river crossing. Where this is very high, it is advisable to support the base by strong drystone toes. To prevent any tendency toward slipping from the sides of the gorge if they are steep, they should be carefully benched, with base slopes inclined downwards from the natural ones so that the earthwork during settlement may tend to move towards the flanks rather than towards the river crossing. If one or both sides of the slopes of the gorge are precipitous, the site is unsuitable for an earthen dam, and, instead, a masonry dam should be constructed at it.

Inferior Foundations.

Nor should an earthen dam be raised on a really bad foundation, as no treatment short of removing all the defective material will enable the work to be safely constructed. Where the foundation is of deep clay, which will become soft when wet, the section will require to be modified. The side slopes should be flattened at the toes to secure a wider base, and steepened a little at the top to reduce the weight. The base of the downstream part of the dam and the area just below it should be carefully drained, and the former, in bad cases, covered with gritty casing material varying from about 5 feet (1.5 m.) thick at the center to about 3 feet (1 m.) at the toes. On the upstream side, the base should be formed with material having half as much grit as is contained by the material on the downstream side, so as to be nearly impermeable.

Drystone Toes.

If the gorge embankment has its sides confined by strong, non-viscous drystone toes up to the base level of the flanks, the enclosed earthwork will be prevented from moving in any direction. After the base of such a gorge dam has been allowed

to attain practically final consolidation by settlement, the upper part can safely be raised on this reliable foundation to the ordinary section of the flank embankment. To give greater frictional resistance to slipping and to prevent the infiltration of water on the upstream side, rubble masonry or concrete toe and core walls should be built into the foundation so as to project into and key with the superstructure (Fig. 3). This type of dam with drystone toes is the one best adapted for embankments exceeding 75 feet in height, and, with them, works may safely be constructed up to 125 feet in height.

Berms.

A berm is a buttress to a dam at its toe, which is the weakest part of the section. The frictional resistance to slipping of

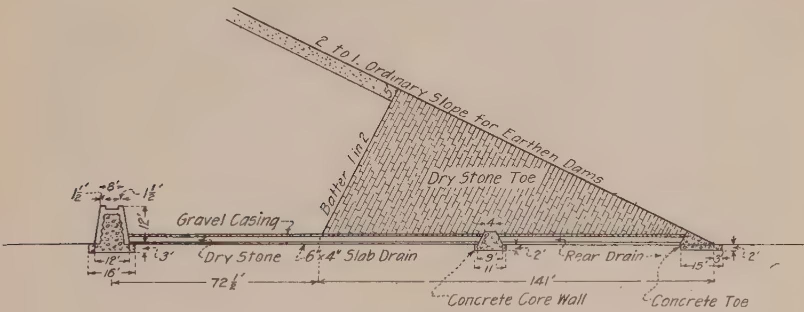

Fig. 3. Downstream Toe.

an embankment is a measure of its weight and is independent of the area of its base, but its cohesive resistance is a measure of that area. A single large berm is thus effective in that it increases the area of the base more than the material in it would do were it distributed evenly, or in a series of small berms, all down the slope. By its great increase of the section of the dam it tends to prevent any dislocation at the top from extending to the base, and to prevent any bulging of the toe; it virtually reduces the height of the dam where that is suddenly increased, as at the river crossing; it forms a toe of dry stable material to a dam with an unduly saturated base; and it can be utilized to carry a roadway, and for passing off the drainage water from rainfall.

The Puddle Trench.

The object of a puddle trench is to interpose a *septum*, as nearly watertight as possible, to prevent the passage through it of water coming to it; it thus tends to keep all the material downstream of it as dry as practicable. Theoretically, a shallow trench near the upstream toe will intercept as much subsoil flow as a deep one at the centre line, and will keep more of the base of the dam dry. For practical reasons the central position for the puddle trench is preferred; there it will not be passed over by excess infiltration from the reservoir, will at first cause only symmetrical and not uneven settlement of the dam superstructure, and will receive the maximum amount of compression by the embankment, which will improve its density and therefore its watertightness.

The section to be adopted for a trench depends partly upon the nature of its filling, and partly upon the nature and extent of the infiltration it has to resist. With true puddle clay a comparatively narrow width will suffice, but as this material is seldom met with in India, greater dimensions have there to be allowed for the inferior material available. Provided the underlying strata are sufficiently watertight, the trench need not be deepened beyond a depth where the filtration through it will be less than that coming to it. It is essential that the trench should intercept such underground flow as would carry away particles of the subsoil and eventually undermine and destroy the dam; it is of less importance that it should be deepened so as to cut off a small amount of harmless leakage which can be dealt with more economically by drainage arrangements. The exercise of sound judgment is, in this matter, a necessity, for a trench cannot be deepened after the dam has been completed.

The direct rate of infiltration in a homogeneous soil decreases from the top to the bottom of a puddle trench, and, therefore, the best section for that work is a truncated wedge, such as an open excavation with side slopes would form. The bottom width must be sufficient to resist the amount of infiltration at its level, and the side slopes must be adjusted to give the filling of the trench a width increasing sufficiently as it rises to stop the greater infiltration which will be met at the higher levels.

To prevent the formation of settlement cracks in the puddle, the trench must not have cross steps in the bed nor projecting shoulders in the sides. It must be bounded by slopes both in longitudinal and cross section, and thus be wedge-shaped, so that the only result of the settlement of the puddle will be to make it more compact and fill the excavation more completely.

Filling the Trench.

The filling should consist of the most retentive clay readily procurable, and gritty material should not be mixed with it, as this will render the mass more permeable and is not required to increase its stability, as it is confined on all sides. The filling must be constructed as a compact mass completely occupying the whole section of the trench, and be quite free from all leakage planes, due either to cracking or to badly consolidated or otherwise porous layers. To insure compactness, only slightly damp material should be used, and this should be thoroughly consolidated, preferably by rollers. To prevent cracking, the different layers should be constructed as rapidly as possible, one on top of the other, and if work is delayed from any cause, the surface attained should be kept moist until the filling can be completed, or if cracked, should then be dug out and remade.

Concrete Trenches and Walls.

Concrete trenches are seldom made in India on account of their expense. Where, however, there is fissured rock below the bed of a trench, a concrete key trench of small width is often carried through it and the concrete top raised a little to project into and key with the puddle superstructure. Comparatively low concrete walls are sometimes constructed across the stream lines traversed, and raised for some height to tongue into the dam embankment.

The Puddle Wall.

The puddle wall, in English practice, is generally made along the centre line of the dam and vertically in connection with the puddle trench. Thus the puddle is reduced to the minimum in amount and is effectually protected from the action of the reservoir and the weather and from perforation by vermin. It may, however, be distorted or broken, by the settle-

ment of itself or by the unequal settlement of the embankment on each side; it cannot be inspected or repaired to any depth; and it tends to keep the dam upstream of it saturated with water.

The puddle wall has also been placed on the upstream slope of the dam so as to form a waterproof coating to it. Here it has the advantage that it will settle regularly with the embankment, can easily be inspected and repaired, and prevents excess infiltration into the whole work. It has, however, the disadvantages that it is not in direct connection with the puddle trench, its volume and cost are at a maximum, it is exposed directly to all external influences, and it may not be able to stand at the ordinary slope of the dam.

When the puddle wall is made in a position intermediate between the centre line and upstream slope, it has advantages and disadvantages between those described above.

In India, puddle walls are not now constructed, on account of their disadvantages. It is there preferred to form the dam as one homogeneous whole; and it is recognized that the puddle wall destroys that homogeneity. Apparently those who favour the puddle wall are influenced by the excellence of the clay at their disposal, and rely upon it to make good the permeability of the general mass of the dam due to its want of artificial consolidation or to the inferiority of its material.

Compared with a masonry core, a puddle wall has the advantages of greater watertightness and greater flexibility: compared with each other, the central type of puddle wall appears to be better than the slope form.

Foundations.

The foundation of an earthen dam, even when moistened by infiltration from the reservoir, should be strong enough to carry the weight of the dam without sensible compression, or if compressible, should be only slightly and uniformly so. It should be of sound, compact and impermeable material free from porous layers and leakage joints and should be so firmly united to the substrata that it will not slip. If these conditions are fulfilled, it is not necessary to obtain for an earthen dam the absolutely rigid foundation which is essential for a masonry dam, and thus sites can be utilized for the former which would either be impracticable or economically impossible for the latter.

The best foundation for an earthen dam is one of compact, unfissured rock, and the next best, one of less compact rock, the unsound parts of which, upstream of the puddle trench, would have to be removed. Rock foundations are best when practically level, but those with a gentle slope may be roughened sufficiently by shallow longitudinal trenches excavated in them, and low longitudinal core walls built on them, so as to prevent the slipping of the dam and to unite it watertight with the rock.

In regard to soils, the more compact and watertight they are, the better. It is advisable to drain the foundations in them, and where the material will soften when wet, it is absolutely necessary to do this. Some engineers prefer a clay seating to one of rock as they consider that the dam will unite in a more watertight manner with it, but sufficient union can be obtained with rock as noted above. All soils which are suitable for the formation of the dam are also good for its foundation: those which are unsuitable for making the embankment are bad for its foundation and should be removed. If on account of their depth this is economically impracticable, the site must be rejected.

The Seating of the Dam.

The maximum amount of leakage from the reservoir and percolation from the interior of the dam tend to find their way along the base of the embankment. The natural surface of the ground, owing to the absence of pressure on it and to the presence of weather influences, is generally not compact enough to be watertight, and unless precautions are taken, the base of the dam may become soddened. The foundation should not only be thoroughly drained, as previously described, but should be prepared so as to secure the stability of the dam and prevent any tendency to slipping. The proposed system of foundation benches is useful not only for drainage but also for obtaining stability, as a dam resting on their sloping surfaces will tend to settle towards its centre line and compress itself, and not away from the centre line and cause slipping. For low and unimportant dams it will suffice to clear off loose surface soil and harrow, or roughen, the exposed surface so that the dam may unite with the underlying compact soil. Similarly, the surface

of the foundation benches should be roughened. At the toes of the dam, where the weight of the superstructure is small, the foundation work may be lessened compared with that under the centre of the embankment.

Material for Construction.

The material for a dam must be both watertight and non-slipping. Soils which are powdery and will not bind, those which are charged with salts or when wet become slushy, and those which when dry break into fragments with sharp edges and smooth, shining surfaces should be rejected. The best natural soils break into tough, not brittle, fragments and have a dull and irregular fracture. The most suitable material is one containing enough clayey matter to enable it to bind and thus become watertight, and enough shaly matter to give it frictional resistance and the property of self-drainage, so that the whole mass never becomes sodden. The proportions recommended are one of clay to one of shale; the soils as they exist should be mixed together accordingly. Pure clay and rich clayey earths are dangerous, as they absorb and retain much water and thus become greasy and liable to slip.

Disposition of Material.

Of the different forms of earthen dams, (c) was described as having a homogeneous section without a puddle wall and as being the one earliest adopted in India. Originally, the embankments were made of black cotton soil throughout, the object being to secure watertightness, but the danger of slipping resulting from its use was not then realized. The more modern practice is to maintain the homogeneity of the section but to form it of earth consisting of one part of clay to one part of shale: with this soil watertightness is obtained by thorough consolidation and the tendency to slipping is avoided. The great advantage of having a homogeneous section is that it will act uniformly as one mass during the process of settlement and self-consolidation; thus will be obviated the formation of internal stresses, owing to the different rates of settlement, which would occur were the section made of different materials. An earthen dam differs from one of masonry in the large amount of settlement which may take place in it; the work should therefore be constructed of material which will allow self-

consolidation to proceed uniformly and, thus, safely. A difference of settlement might result in a slip and might, anyhow, affect the disposition of the materials of the dam and lead to cracks, leakage planes and irregularities. Moreover, there is the practical advantage attending the use of a uniform material, that thereby construction is made easier.

If, however, on account of the scarcity of one kind of soil and the abundance of another, it would not be economical to use the same mixture throughout, the upstream part of the dam should be made richer in clayey, and the downstream part, in shaly material, the change in constitution being gradually varied throughout the section. The former will thus gain in watertightness and the latter in stability at the expense of the greater tendency to unequal settlement and greater difficulty in securing correct proportions throughout the mass. Thus all sound spoil can be utilised in constructing the dam, even rocky dèbris can be disposed of at the toe of the downstream slope, where it will add stability by its weight.

Casings.

Owing to their narrow width, the casings do not affect the settlement of the dam; their object is to protect the interior from exterior influences. The upstream one forms a firm and insoluble foundation for the pitching, and the downstream one, a covering which will not be cracked by the sun nor guttered by the rainfall. The casings should consist of one part of clayey to two parts of shaly material.

Construction of the Dam.

The method of constructing the dam is—first to wet slightly the layer last completed; on the moistened surface to spread and mix the material of the new layer, and then to consolidate it. On the completion of a layer, the process is to be repeated similarly for the next one, and so on.

Watering.

When clay is wetted it expands and thus becomes more porous, softer and inclined to slip; moreover, when once wetted it takes a long time to dry. It is therefore necessary, in the interest of the watertightness and stability of the dam, to limit the water used to the amount just sufficient to unite the new layer with the old one, so as to produce a solid mass free from

stratification, which is the sole object of watering the earthwork.

Spreading and Mixing.

The purpose of spreading and mixing the soils of which the dam is formed is to obtain a uniform material evenly disposed and thoroughly incorporated, by hand or by harrows, so as to avoid stratification. Were mixing not done, the clay might form slipping planes and the shale, leakage planes, and both of these might endanger the safety of the work. The layers should have small thickness, so that they may be properly consolidated, and should be formed with slopes toward the centre of the dam, to give the earthwork a tendency to slip inwards rather than outwards.

Consolidation.

In order to render the earthwork thoroughly and uniformly dense, it should be consolidated artificially, as much as possible, and evenly throughout the section. Thus the final consolidation due to settlement will be less in amount, and during it the earthwork will remain regular, the layers will be maintained unchanged, and the formation of leakage and slipping planes will be prevented. An originally loose structure will at first be subject to great infiltration from rain and from the reservoir which will keep it green for a long time, and this will tend to cause great and unequal settlement (due to the variation in the heights of the cross section) and offer less resistance to further infiltration during the process of self-consolidation of the dam. Artificial consolidation during construction is, therefore, of the utmost importance, and the more thoroughly it can be done, the better: it is the chief means whereby is resisted percolation, the principal danger to earthen dams. As a further precaution in the same direction, the dam should be allowed to self-consolidate in the dry for as long as possible before it is subjected to infiltration from the reservoir.

Slips.

A slip of a dam is usually the result of excessive percolation into it, which either soddens and softens its base so that it cannot support the embankment, or penetrates fissures and leakage planes, whereby a portion of the earthwork is detached from the main mass. Every precaution should, therefore, be

taken during the formation of the dam to prevent a slip by proper preparation of the foundations, careful selection, mixture and consolidation of the materials, uniform and slow construction and thorough drainage. Even greater care is required in repairing a slip; and, in particular, great care should be taken to drain it thoroughly.

Slips in Pure Clayey Soils.

A slip in such a soil has a smooth, unctuous surface, and parallel planes of similar surface are formed for some feet on each side of it. It is doubtful if these will ever disappear of themselves; the result is that the fallen mass rests on a series of steeply-tilted, smooth, lubricated planes, and is itself traversed by minor slipping planes and by fissures which will admit rainwater and reduce the frictional and cohesive resistance to motion. No dependence can, therefore, be placed on it, and the only sound system of repair consists in entirely removing it and in replacing it by trustworthy material.

Slips in Gritty Soil.

When a slip occurs in earthwork having proper proportions of clay and grit, the latter will enable the whole to reunite gradually by self-drainage and settlement, but the junction will always be a plane of weakness. To aid that self-drainage, the first repair operation is to drain the slipped earthwork by drains along the junctions with the stable part of the dam, and intermediate ones at right angles to its centre line. The excavation should be taken out in timbered trenches and the refilling should consist of highly gritty, self-draining clay, with base drains leading out of the dam. The next step is to construct a strong, well-drained, drystone wall, parallel to the axis of the dam, extending throughout the slip into the stable flanks, and with good batters against the slip so as to increase the stability of the new earthwork. If the fallen earthwork at the toe is to be removed entirely, this wall may be placed about the centre of the width of the slip; if that is to be allowed to stay, the wall should be built at its toe. To add to the stability of the repair, a strong and well-drained berm should be formed just beyond the original toe of the dam, and its own toe should be secured by a second drystone wall. All these drains and walls should, if possible, be founded on

rock, but where this is not met at a reasonable depth, they should be carried well into the natural subsoil and beyond the limit of disturbance caused by the slip. All open excavations should be taken out in sections, with sufficient widths of undisturbed material between them to act as buttresses, and should be filled as quickly as possible.

Pitching.

Drystone pitching is the form generally adopted in India and has the merits of reliability, durability and cheapness. It is laid on a layer of quarry spauls the object of which is to prevent the entry of burrowing vermin, the growth of plants and the lapping action of water finding its way through the interstices of the stones, which would, otherwise, wash out the underlying earthwork and undermine and destroy the continuity of the pitching. The defects to be avoided in pitching are: unsound material; larger base of stone laid uppermost; long, unbroken joints; stones set with the longest dimensions of their bases not roughly parallel to the centre line of the dam; sharp abutting edges, involving large interstices; stones projecting irregularly; loosely placed stones; partial bedding of bases of stones; bad fitting of bases of stones; loose packing and incomplete filling of interstices.

Such pitching has not a very sightly appearance; it cannot be examined quickly, and it has interstices between which waves may act and vermin penetrate. To remedy these defects, the interstices might be completely filled with fine concrete, or coarse mortar, so as to unite the stones into a solid covering.

Concrete pitching is not used in India on account of its expense and inferior durability. It may be made of separate slabs or *in situ;* in the latter case the embankment should be well wetted beforehand so as not to absorb water from the concrete and cause it to perish. The pavement should be laid in sections with free joints (so that it may follow the movement of the dam) and on quarry, spauls to give it a rough bed from which it will not slip; to assist the spauls, header stones might be inserted at intervals through the concrete into the earthwork.

THE WASTE WEIR.

General Remarks.

The site available for the waste weir usually determines whether the storage work is possible or not; the essentials required for it are sufficient length, a flat longitudinal and a gently sloping cross-section, hard strata, the proper elevation, and a good outfall. The length is necessary to get discharging capacity; the flat sections and hard strata, to diminish the cost of the works and to obtain security for them; the elevation of the weir crest is determined by considerations of storage; and the good outfall is wanted so as to lessen damage by floods. The best site is generally on a long, level ridge of hard material with a gentle slope downstream.

It is essential that the waste weir should be able to discharge the maximum flood possible, and, as it constitutes the safety valve of the reservoir, that discharge must not be underestimated.

(a) Where flood observations have been recorded for 25 years, an allowance of 10 per cent over the highest known flood should be made to provide for an abnormal flood: where the record is shorter, the allowance should be greater.

(b) When a reservoir is downstream of another one which may breach, or is liable to be visited by a cyclone, extra flood provision should be made for the abnormal discharge which may thus reach the work. That provision may consist in lengthening the waste weir, or in forming safety waste weirs and breaching sections in addition.

(c) The discharging power of a waste weir depends upon the unobstructed normal width of its approach channel and of the portion of its tail channel just downstream of its crest.

Forms of Weirs.

The usual forms of waste weir are:

(a) A drowned channel, or simple excavation, with or without a crest wall. This type is best adapted to sites with soft soils which would be liable to be eroded by an overfall.

(b) A drowned waste weir. This is generally of small height and has the crest of its weir-wall below the high-flood surface of the tail channel. It may be converted into (c), when practicable and desirable, by deepening the tail channel so that its high-flood surface is below crest level. This form will be required when the levels necessitate it, and it also is useful for soft soils.

(c) A clear overfall weir. This is one having the crest of its weir-wall above the high-flood level of the tail channel; it has the greatest discharging power per lineal foot and is thus adapted to sites of restricted length. It requires good foundations, and where these do not exist, protection by a water cushion and curtain walls across the tail channel.

Positions of Weirs.

In respect to their positions, waste weirs may be classed as:

(a) Flank weirs, at the immediate flank and in continuation of the dam embankment

(b) Saddle weirs, separated from the dam by high ground

Flank weirs are the less safe form, as the discharge from them may outflank and injure the dam: to prevent this a wing wall is required on the upstream side and a lining wall on the downstream side of the embankment.

Saddle weirs discharge clear away from the dam which therefore does not need protection; but to obviate the outflanking of the weir itself, masonry flanks on one or both sides of it may be necessary.

THE OUTLET.

General Remarks.

The outlet should be located at the most suitable site on the line of the dam, and the alignment of the head of the canal from it adjusted accordingly. For an outlet through a dam the best position is at the centre of a saddle, or depression, across the centre line of the embankment, as then the earthwork will settle symmetrically on both sides of it, and any underground percolation that may exist will find its way to the

depression. The worst position for such a work is on steep sidelong ground, and particularly on the side of the river gorge, as there it will be unsymmetrical with the dam, the lower side of which will tend to move away from it, and the underground percolation, by lubricating the whole base downstream, will increase this tendency. When practicable, excellent positions are near a flank of the dam or near a cross ridge from its centre line, as then the approach bank to the outlet can be raised on natural ground, and not over the outlet tunnel, and will thus be independent of that.

To ensure safety, the outlet should preferably be founded on sound rock; if that is not available, on a sound, hard, insoluble stratum; failing these, the foundations should be carried down deep and should consist of a wide concrete base. In order to secure the best foundations, to cross the line of the puddle trench safely, and to prevent any settlement of the dam from affecting the outlet, it is best to have the top of the culvert some depth below ground surface. The culvert must never cross the puddle trench above its bed, as that would prove an unreliable foundation owing to its compressibility and would thus lead to the fracture of the outlet. Where the ordinary foundations of that work are above the bed of the trench, the puddle must be replaced by masonry, or concrete, so as to make a secure foundation for the culvert.

The Level of the Sill.

In fixing this level it should be remembered that:

(a) Space should be provided below the outlet sill for the accumulation of silt in the reservoir—in India about 10 per cent of the gross storage capacity is allowed for this space;

(b) The capacity of the lower contours of a reservoir is relatively small compared to that of the upper ones; it is, therefore, generally not worth much extra expense to utilize the former;

(c) The lower the sill, the greater will be the cost and insecurity of the outlet;

(d) The higher the sill, the quicker, usually, will the channel from it gain command and the shorter will be its course.

Culvert Under the Dam.

There are several forms of outlet, but in India the one generally adopted is that having a masonry culvert under the dam with an outlet tower, or headwall, at its upstream end (in which are the sluice valves and regulating apparatus) connected to the dam by an approach bridge and bank. This is an economical form, but as the culvert is buried under the dam, it is absolutely necessary to have it well designed and soundly constructed, otherwise, failure of both works will result: since the building takes place in the open, it can easily be supervised.

The trench excavated for the culvert should be considerably wider than the masonry and should be taken out with sloping sides: the space not occupied by the culvert should be filled with good watertight earthwork. Pure puddle in this position is objected to by some engineers as they consider it increases the stress on the culvert and may cause it to crack.

The section usually adopted for the culvert is an inverted ovoid, with the wide part as invert, so as to secure a broad base and give the work the largest discharging capacity. The culvert should have a longitudinal slope of about 1 in 100 to facilitate drainage and the flow of the discharge. For the semi-circular invert, a flat pavement may be substituted: this should be constructed of large stones, laid parallel to the axis of the culvert, which should break joint, be well keyed under the arch ring and should be set in cement mortar and founded on concrete. Staunching rings should be built on the centre line of the dam, and upstream of this, to prevent the creep of water. Downstream of the one at the centre line of dam, the arch ring should be cased with drystone for drainage purposes.

Headwall on the Centre Line of the Dam.

This consists of a short length of masonry dam, or headwall, inserted in the embankment and staunchly connected thereto by a long staunching wall on each side. At the ends of the headwall are four long wing walls which preserve a passage for the water which is discharged out of the reservoir through sluices pierced in the headwall. The design is rather dearer than the ordinary culvert form but has several advantages over that, as it can easily be inspected and repaired (be-

ing in the open), and can have a large discharging capacity, which will aid the waste weir and allow the reservoir level to be lowered rapidly when necessary.

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DISCUSSION

Mr. Jorgensen.

Mr. Lars R. Jorgensen,* M. Am. Soc. C. E. (by letter), stated that in his very able discussion of earthen dams the author has barely touched upon the earth and rock-fill type of dam, one used to quite an extent in the United States and regarded by many engineers as equal in safety to masonry dams.

In rock-fill and earth dams, the rock-fill is of course placed on the down-stream side of the dam and the earth on the up-stream side, the earth being graded from coarse material next to the rock-fill to fine material next to the water-face. The rock-fill affords a good opportunity for drainage; it is heavy, and therefore stable; and rain will not affect the down-stream face. Provided the rock for building it be available, such a dam can be built instead of an earthen dam on almost any site; and it does not necessarily need to be founded upon a solid-rock foundation.

He is much interested in the method of drainage and of stepping off the foundation shown in Fig. 2. The method is somewhat more elaborate than ordinarily used in the United States, but ought to give a first-class result. On page 736 the author states that an earth dam cannot be built in a gorge with precipitous side-slopes: why cannot the method of stepping off as shown for foundations in his Fig. 2, be used for the sides also? If the gorge is precipitous the site surely will be

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Mr. Jorgensen. solid rock, and the most logical core-wall would seem to be of concrete, which easily could be tied to the vertical side walls in a water-tight manner. If a puddle core-wall had to be used, it seemed to Mr. Jorgensen that by cutting a more or less deep vertical slot in the vertical sides, sufficient provision against leakage around the ends of the core-wall could be secured.

It is true that a clay core-wall does not divide an earth dam in two parts to so great an extent as does a concrete core-wall, and the former therefore has some advantage in this respect; but so far as water-tightness is concerned, he cannot agree that a puddle core is more water-tight than one of concrete, because a concrete slab tied to the rock foundation and sidewalls can be made water-tight. In this connection, good material and a rich, correctly proportioned concrete count very much more in a core-wall than mere thickness. When reinforced with steel, such a slab should be fairly flexible.

The author's statement about "slips" is very valuable, as is his paper as a whole.

Gen. Chittenden. **Gen. H. M. Chittenden,*** M. Am. Soc. C. E. (by letter), stated that he would touch upon only a single feature of the author's very complete paper.

The author's only serious criticism of the hydraulic method of building earth dams relates to the period of construction. If the two faces of the dam are made strong enough to sustain the central semi-liquid fill until the embankment is complete, and if time be allowed for draining off the surplus water in the fill, then the dam would seem to be secure against the infiltration of water when it comes to filling the reservoir. General Chittenden sees no reason why a judicious application of the sorting effect of water in building a dam is not a desirable substitute for the old process of compacting by mechanical means. The former method is less liable to leave defective work undiscovered.

The author has laid so much stress upon the importance of excluding any considerable amount of water from the body of earth dams, that it would be of interest to know his opinion as to the effect of non-use upon earth dams built for so-called detention reservoirs, such as those proposed in the flood-control of the Miami River, Ohio. The immense reservoirs proposed there are to be formed by massive earth dams, with open sluiceways which will carry off all ordinary flow and will empty the reservoirs rapidly whenever excessive rains fill them temporarily. The reservoirs probably will not fill entirely once in a quarter of a century, but nearly all the time will stand as huge embankments without any pressure against them. How will this status affect the stability of the dam, and is there any liability that weakness will develop from cracks through too great drying out of the embankment? From the author's point of view, it would seem that such a condition would affect the stability of earth dams favorably.

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Mr. Strange.

Mr. W. L. Strange, in reply to Mr. Jorgensen, stated that, as his paper dealt with earthen dams and had necessarily to be compressed, he did not in it mention rock-fill and earth dams. He agrees with Mr. Jorgensen as to the advantages possessed by the latter dams; the earthen dam with dry-stone toes mentioned in the paper shares these, and, in addition, is supported at the base of the upstream face, which is of importance in the case of a high dam. In a purely rock-fill dam it is necessary to construct the upstream portion solidly, as on it the safety of the whole structure depends. It would seem advisable to place some fine material near the downstream face in order to induce silting of the interstices of the stones upstream of it so as to make the mass staunch.

As noted in the paper, it is highly desirable to bench the slopes of a gorge when these are moderately steep. Where the slopes are excessively steep, and certainly where they are precipitous, benching is not likely to secure the dam from slipping, as the earthwork as a whole will be resting on highly-tilted planes that are sure to become lubricated by percolation water which will not be entirely cut off by leakage-preventive works, however carefully designed and constructed.

The author's statement that a puddle wall had greater water-tightness than a masonry core wall had reference to walls of equal cost: In India puddle could, without excess, be given a volume eight times as large as masonry and would then be more water-tight than it.

In reply to General Chittenden, the author would remark that, given sufficient time for self-drainage, a hydraulic-fill dam might become as resistant to subsequent infiltration from the reservoir as one constructed by the ordinary dry method. It might, however, not be possible to allow such time, which would be considerable, and then the partially drained deposit would rapidly absorb water by infiltration; its final consolidation would thus be long deferred, and until complete, the stability of the hydraulic-fill dam would be less than that of a dam formed in the dry, which, if made of proper material thoroughly consolidated, as it should be, should be free from defective work.

Dams of detention reservoirs which seldom fill if they are situated in areas visited by rainfall should have their interiors kept moist by infiltration of the rain; if, however, they are located in rainless areas, the occasional filling of the reservoirs should produce a soakage which would render the bulk of the earthwork sufficiently damp for many years. Hence in both cases such dams probably exist under favourable conditions for stability. To aid the retention of moisture it would seem advisable to make dams constructed in the latter areas richer in clay than those built in the former localities.

In conclusion the author would express his gratification with and thanks for the general remarks made as to his paper.